ATTACHMENT 1

PROPOSED AMENDMENT TO LCO 4.1.9

Basis for Specification LCO 4.1.8

An unexpected and/or unexplained change in the observed core reactivity could be indicative of the existence of potential safety problems or of operational problems. Any reactivity anomaly greater than 0.01 ΔK would be unexpected, and its occurrence would be thoroughly investigated and evaluated. The value of 0.01 Δk is considered to be a safe limit since a shutdown margin of at least 0.01 Δk with the highest worth rod pair fully withdrawn is always maintained (see LCO 4.1.2).

Specification LCO 4.1.9 - Core Region Temperature Rise, Limiting Condition for Operation

Whenever core inlet orifice valves are set for equal region flows, the total circulator flow rate shall be above the minimums given in Figure 4.1.9-1 (at the appropriate helium density and power level). Whenever the core inlet orifice valves are set at any positions other than for equal region flows, the measured helium coolant temperature rise through any core region shall not exceed the limits given in Figure 4.1.9-2 (at the appropriate helium density and power level).

If the measured helium coolant temperature rise exceeds the allowable limits or the minimum total circulator flow rate is not available, immediate corrective action shall be taken. If this corrective action is not successful within fifteen (15) minutes, an immediate orderly shutdown shall be initiated.

When the reactor is already shutdown and it is necessary to terminate the helium flow for short time periods, the amount of thermal energy from fission product decay must be sufficiently low to prevent the average core temperature from exceeding 760°F during the period of no flow.

Basis for Specification LCO 4.1.9

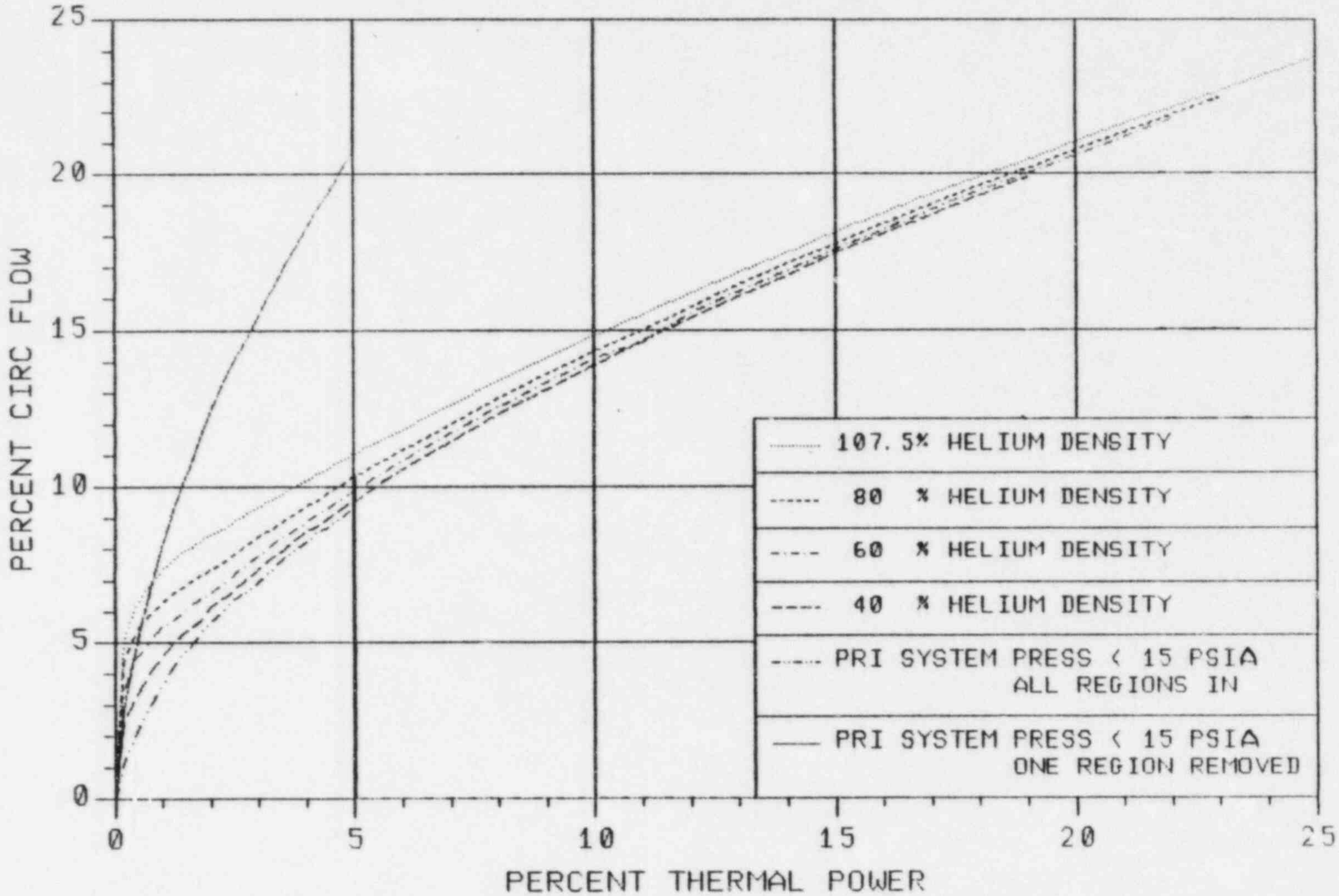
The intent of this specification is to assure that there is an adequate helium coolant flow rate through all core coolant channels, particularly for low power and flow conditions. This is accomplished by specifying either a minimum total circulator flow rate, or a maximum core region coolant temperature rise for various thermal power levels (including power from decay heat).

Very low helium coolant flow rates may result in laminar flow conditions with resultant high friction factors and low heat transfer film coefficients and potential for possible local helium flow stagnation, which could result in excessive fuel temperatures.

The minimum total circulator flow and maximum core region helium temperature rise limits have been developed based upon a number of conservative assumptions. The maximum column to region average power peaking factor was assumed to be 1.61 which is consistent with LCO 4.1.3. The analysis for full density conditions assumed the maximum permissible primary coolant inventory of 107.5% specified in LCO 4.4.1. The analysis was performed for each power level at a core inlet temperature of 100°F, and then in increments of 50°F up to 750°F. The most restrictive of these calculations at each power level were utilized to form the limits. Model uncertainties and measurement errors were factored into the analysis.

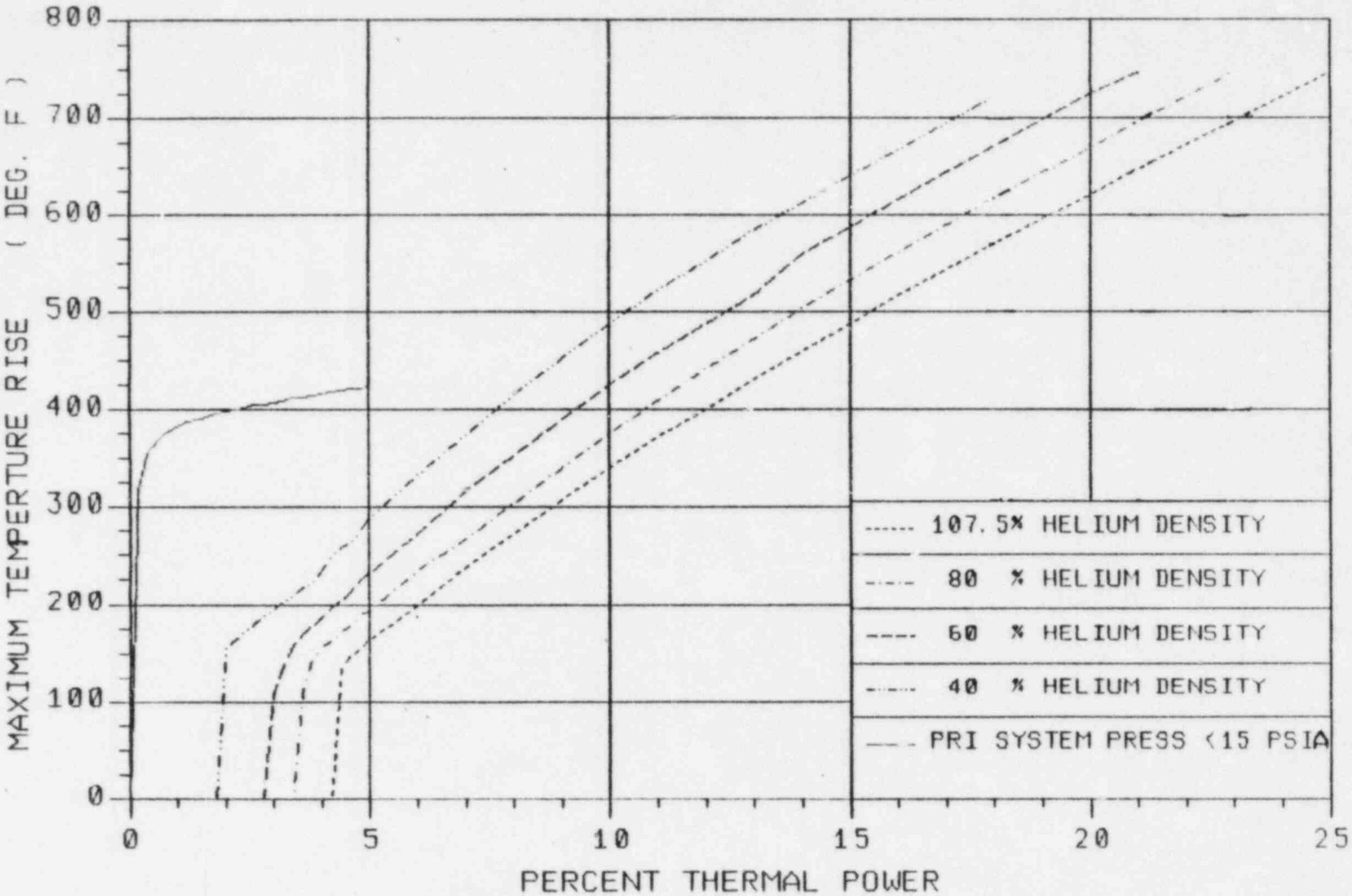
Even with the reactor shutdown, some helium coolant flow must be provided to remove the heat from fission product decay. The flow must be sufficient to prevent the helium inlet temperature from exceeding 760°F to prevent damage to the reactor internals. If the flow is terminated for short periods and the average core temperature does not exceed 760°F, the helium inlet temperature will be acceptable when the flow is resumed.

Figure 4.1.9-1



$$\text{* Helium Density} = \frac{0.373\ [\text{Reactor Press (psia)} / (\text{Circ Inlet Temp } (°F + 460))]}{0.00213}$$

Figure 4.1.9-2



$$\% \text{ Helium Density} = \frac{0.373\ [\text{Reactor press (psia)} / (\text{Circ Inlet Temp } (°F + 460)]}{0.00213}$$

ATTACHMENT 2

GA DOCUMENT NO. 907212

LCO 4.1.9 ANALYSIS

GA [illegible] (REV. 11/80)

CALCULATION REVIEW REPORT

TITLE: LC04.1.9 REANALYSIS

APPROVAL LEVEL 2

QAL LEVEL I

DISCIPLINE	SYSTEM	DOC. TYPE	PROJECT	DOCUMENT NO.	ISSUE NO./LTR.
M	18	CFL	1900	907212	A

INDEPENDENT REVIEWER:

NAME Paul Symolon

ORGANIZATION 647

REVIEWER SELECTION APPROVAL: BR MGR H Jones DATE November 22, 1983

REVIEW METHOD:	YES	NO	ERROR DETECTED
ARITHMETIC CHECK	X		None
LOGIC CHECK	X		None
ALTERNATE METHOD USED		X	
SPOT CHECK PERFORMED		X	
COMPUTER PROGRAM USED		X	
ΔP Equation Derived	X		None

REMARKS: (ATTACH LIST OF DOCUMENTS USED IN REVIEW)

The ΔP equation in 907212/A used for the laminar instability analysis was derived from fundamental principles, and was found to be correct. A check was made to be sure that it was correctly implemented into the LAMSTAB code. The hand calculations of APPENDIX A were all checked, and the equations for uncertainty in the code were found to be consistent with APPENDIX A. An overall logic check of the code was also made

CALCULATIONS FOUND TO BE VALID AND CONCLUSIONS TO BE CORRECT:

INDEPENDENT REVIEWER Paul Symolon DATE 11/22/83
SIGNATURE

GA 1485 (REV. 10/82)

GA Technologies Inc.

ISSUE SUMMARY

TITLE: LCO 4.I.9 Reanalysis

☐ R & D
☐ DV & S
☒ DESIGN

APPROVAL LEVEL 2

DISCIPLINE	SYSTEM	DOC. TYPE	PROJECT	DOCUMENT NO.	ISSUE NO./LTR.
M	18	CFL	1900	907212	A

QUALITY ASSURANCE LEVEL	SAFETY CLASSIFICATION	SEISMIC CATEGORY	ELECTRICAL CLASSIFICATION
I	FSV I	FSV II	NA

ISSUE	DATE	PREPARED BY	APPROVAL: ENGINEERING	APPROVAL: QA	APPROVAL: FUNDING PROJECT	APPROVAL: APPLICABLE PROJECT	ISSUE DESCRIPTION/ CWBS NO.
A	NOV 23 1983	R.Kapernick (signed 11-22-83)	K. Asmussen (signed 11-22-83); H. Jones (signed 11-22-83)	For D.Pettycord (signed 11/23/83)			Initial Release 2970210004

RELEASED

CONTINUE ON GA FORM 1485-1

Text: 1 → 63 = 63
Comp.
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516 pages

NEXT INDENTURED DOCUMENTS

N4565

REV																												
SH																												
REV																												
SH	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
REV																												
SH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28

TITLE: LCO 4.1.9 REANALYSIS

DOCUMENT NO. 907212	ISSUE NO./LTR. A

TABLE OF CONTENTS

SUMMARY

The reactor operating limit to prevent laminar flow instability in the reactor core, LCO 4.1.9 of the Technical Specifications, was reviewed. Non-conservative errors and omissions in the development of the original limit were found, and as a result new operating limits have been defined. The new limits are more restrictive than the current operating limits, and will necessitate incorporation of the modification to the limit recommended in References 1 and 2 for reactor startup. This modification permits the opening of 2-10 orifices from the uniform flow positions, provided the reduction in flow in the other regions is offset by an increase in total core flow.

A remaining concern in the laminar flow instability limit, which has been adversely affected by the new, more restrictive curves, is the violation in this limit following a reactor scram or rapid reduction to low power operation. It is believed the only way to prevent this violation is to increase the time for successful corrective action from 15 minutes to about 2-3 hours. This would provide the reactor operator with sufficient time to stabilize the plant from the transient, and then later to adjust the orifices back to the uniform flow positions. Justification to increase the time for successful corrective action would require additional analysis.

INTRODUCTION

The onset of laminar flow instability occurs when the change in pressure drop with mass flow rate becomes negative. The potential for laminar flow instability in a HTGR reactor was studied by Boyack (Reference 3). Based on his work, a limit of FSV reactor operation was developed which related the permissible region temperature rise to reactor power (Reference 4). Subsequently, additional analysis was performed to define the operating limit in terms of minimum reactor flow vs. reactor power (see Reference 5). This limit was easier to meet, which was necessary for operation up to about 5% power. However, for this limit the region orifices needed to be adjusted for near equal flow per coolant channel.

After considerable reactor operating experience, a modification to the operating limit was proposed (Refs. 1 and 2), which would permit the opening of a few orifices beyond their uniform flow positions. The objectives of this modification were to permit reactor startup and operation with a few orifices inoperable (provided the region temperature mismatch limits of LCO 4.1.7 could be met) and to facilitate the change from equal flow orifice positions to equal exit gas temperature orifice positions. The latter objective was in anticipation of the additional flow which would otherwise be required during startup in later cycles, when the core power distribution would be more skewed.

Note that this proposed modification did not change or challenge the basis for the original limit. The new curves ensured that the minimum coolant channel flow would not be less than that required to meet the original limit.

Recently, the bases and various assumptions in the development of the laminar flow instability limit were reviewed and several non-conservative errors and omissions were found. As a result, a reanalysis was performed and new operating limits defined. This report documents the new analysis.

RECOMMENDED NEW FIGURES

Proposed new limits for LCO 4.1.9 are shown in Figures 1 and 2. The changes that have been made are enumerated below:

1. The effect of different density gases in the upper and lower reflectors has been accounted for. It was thought that this term had been included in the original analysis (see equation 3 of Reference 4). However, based on a recent review of the original analysis, it appears that this term had been omitted (Reference 6). Note also that the gravity term in this equation is slightly in error (Reference 7). The correct term is given in the next section.

2. The maximum column to region average power peaking factor (TILT) was increased from 1.44 (used in the original analysis) to 1.61, to be consistent with the limit given in LCO 4.1.3 of the Fort St. Vrain Technical Specifications.

3. The number of coolant holes in the core was increased from 23,550 to 24,133. The calculation for the number of coolant holes is given in Appendix A.

4. The analysis was performed at the maximum permissible primary coolant inventory of 107.5% specified in LCO 4.4.1 of the Technical Specifications. The original analyses had been performed at nominal coolant inventory.

5. The Reynolds number, used to calculate the friction factor in the pressure drop equation, was evaluated locally in the coolant channel. Thus, onset of laminar flow instability may be predicted even though flow entering the coolant channel is turbulent. For the original analysis, the friction factor for the entire channel had been calculated using the Reynolds number at channel inlet (see Reference 7).

6. The analysis was performed over a core inlet temperature range from 100°F to 750°F. At each power level, a calculation was performed at a core inlet temperature of 100°F, and then in increments of 50°F up

to 750°F. The most restrictive calculation at each power level was used to form the limit. It is belived the core inlet temperature was fixed at 100°F for the original analysis.

7. In the original analysis, a ratio of 1.2 had been assumed between the flow in an average channel and that in the critical channel. In this analysis this ratio was determined for every core operating condition considered, by first calculating pressure drop in the average channel (where the flow is known), and then calculating flow rate in the critical channel with this pressure drop.

   Note that for the LCO 4.1.9-1 (Figure 1) limit, the relationship between the flow rates in the two channels is a function of the core orifice settings. With more open core orifices, the ratio between the average and peak power channel flows increases. For Figure 1, an orifice setting of 20% open for a 7-column region was used. The reason for this is given in item 8 below.

   Figures 3 and 4 show the flow defect factors that were calculated for the limits given in Figures 1 and 2. The factors shown in these figures are not always the largest calculated at a given power level. They are the factors which come from the core inlet temperature for which the most restrictive limit was derived.

8. The models which relate local coolant temperature rise and flow to total core power and flow (for Figure 1), or to total core power and region temperature rise (for Figure 2) are developed in Appendix A. These are based on the reactor flow diagram shown in Figure 5. Values for the flow rates and heats in the various flow paths that were used are given in Table 1. The new values were taken from Reference 8 and are generally higher than those used in the original analysis.

   As discussed in Reference 8, the core bypass flow fraction is a function of the degree to which the core is orificed. Also, as noted in 7 above, the flow detect factors are a function of the degree of core orificing. For more open orifice positions, the core bypass flow fraction decreases but the flow defect factor increases. To understand the relationship of these two factors on the laminar instability limit, an analysis was performed for a range of orifice positions form 8% to 20% open and for a core inlet temperature of 100°F. The results of this analysis are shown in Figure 6. As can be seen, the most limiting case is with an orifice position of 20% open. Based on this analysis, the LCO 4.1.9-1 limit was developed for the 20% open orifice position case, and the limit is valid for orifice settings from 8% to 20% open.

The core bypass flow fractions for this evaluation are given in Table 2. These were obtained by performing a POKE analysis to determine core pressure drop for each assumed orifice position and then using the expression for bypass flow as a function of pressure drop from Reference 8 to determine bypass flow. Note that since bypass flow fraction is also input to POKE, this analysis had to be performed iteratively. Also, the analysis was performed at 100% power and flow, but subsequent analysis at several low power and flow conditions showed the calculated bypass flow fraction is not sensitive to the assumed core power and flow.

The core bypass flow fraction for the 20% open orifice position case was also used in the analysis for the LCO 4.1.9-2 limit. This case was used because, due to the limited range of flow control of the orifices, closing the orifices beyond 20% open leads to core flow resistances where the low power (critical) region is necessarily overcooled.

9. Relationships were developed to account for uncertainty in these models and measurement errors, which were factored into the analysis. These relationships are also developed in Appendix A. Estimates for uncertainty in the various parameters are given in Table 1. The uncertainty estimates are believed to be conservative, given the considerable operating experience at Fort St. Vrain. In the previous Figure 1 limit (core flow vs. core power) the minimum core flow had been increased by 25% as a factor of conservatism. This factor is larger than that obtained from the uncertainty analysis, by ~10% to 15%. In the previous Figure 2 limit no factor of conservatism had been used.

DATA INPUT AND ANALYSIS

The complete expression for the coolant channel pressure drop that was used is as follows:

$$\Delta P = \frac{\omega^2}{2g_c\ \rho A^2}\left[Kin + Kout\ \tau + 2(\tau - 1) + \frac{4f_{UR}L_{UR}}{d} + \frac{4f_{LR}L_{LR}}{d}\ \tau + \frac{4f_T L_{CT}}{d}\ \frac{\tau_T^{\ mb_T+2} - 1}{(\tau_T - 1)(mb_T+2)} + \frac{4f_L L_{CL}}{d}\ \frac{\tau_L^{\ mb_L+2} - 1}{(\tau_L - 1)(mb_L+2)}\ \tau_T \right]$$

$$\rho\ \frac{g}{g_c}\left[L_{UR} + L_C\ \frac{\ln\ \tau}{\tau - 1} + L_{LR}\ \frac{1}{\tau}\right]$$

where

K_{in} = inlet loss coefficient

K_{out} = exit loss coefficient

L_{UR} = length of the upper reflector

L_{CT} = portion of the active core length where flow is turbulent

L_{CL} = portion of the active core length where flow is laminar

L_C = length of the active core (= $L_{CT} + L_{CL}$)

L_{LR} = length of the lower reflector

d = coolant channel diameter

ω = coolant channel flow

g_c = Newton constant

g = gravitational acceleration

ρ = coolant density at channel inlet

A = coolant channel area = $\frac{\pi d^2}{4}$

τ = T_{exit}/T_{inlet}

τ_T = T_{tran}/T_{inlet} (an expression for T_{tran} is given below)

τ_L = T_{exit}/T_{tran}

f_{UR} = friction factor in the upper reflector

F_{LR} = friction factor in the lower reflector

f_T = friction factor at the active core entrance (if turbulent)

f_L = friction factor at the point in the active core where the flow becomes laminar

m = constant in the expression for coolant viscosity (see below)

b_L = constant in the friction factor expression for laminar flow (see below)

b_T = constant in the friction factor expression for turbulent flow (see below)

This is essentially the same equation as given in Reference 4 (equation 3). The differences are that the friction factor contribution in the active core has been integrated separately over the turbulent and laminar regimes and the gravity term has been corrected.

This equation was programmed into a code called LAMSTAB*RJK. Appendix C contains a listing of the code and a sample input. The analysis in LAMSTAB*RJK proceeds as follows:

1. For LCO 4.1.9-1 the circulator flow rate must be greater than a specified minimum value, which is a function of the core inlet temperature and the core power fraction. For a given core inlet temperature, calculations are performed for a range of core power fractions from zero to where the minimum core flow is such that a core power to flow ratio of 1.05 is obtained. Calculations are repeated for the specified range of core inlet temperatures. The LCO 4.1.9-1 limit of circulator flow rate vs. core power fraction is formed by taking the maximum flow rate required at each core power fraction over the range of core inlet temperatures.

2. For each combination of core inlet temperature are core power fraction, the limiting circulator flow fraction is obtained iteratively. Initially, a low value of circulator flow is taken and the core pressure drop is calculated. This calculation is repeated with increasing values of circulatow flow, until the condition producing $d\Delta p/dm = 0$ is found.

3. The Δp in the expression above is the coolant channel Δp. To obtain this value, the total core pressure drop is first calculated, using an average power channel in the core (since the flow rate in this channel is known). Once the total core pressure drop is known, the pressure drop equation can be solved iteratively for the high power channel to determine the high power channel flow. The coolant channel Δp for this channel is then determined by subtracting the pressure drop through the orifice.

4. The flow rate and temperature rise in the average or high power channel are related to the circulator flow and reactor power as given in Appendix A. Once flow rate and temperature rise in the channel are known, the pressure drop equation is solved in a relatively straightforward manner. To determine the friction factor, the point of relaminarization may be calculated as follows:

$$N_{RE}(tran) = \frac{4\omega}{\pi d \mu}$$

where $N_{RE}(tran)$ = the transition Reynolds number

μ = coolant viscosity

$= \mu_o T_{tran}^{m}$

T_{tran} = coolant temperature at transition

μ_o, m = coefficients in the coolant viscosity expression

From the Reynolds number equation the transition temperature may be calculated:

$$T_{tran} = \left[\frac{4\omega}{\pi d \mu_o N_{RE}(tran)}\right]^{1/m}$$

Depending on the channel temperature rise, flow may be wholly laminar, wholly turbulent or partially turbulent and laminar. If the flow is partially turbulent and laminar, the portion of the active core that is turbulent is calculated from:

$$L_{CT} = \left[\frac{T_{tran} - T_{inlet}}{T_{exit} - T_{inlet}}\right] L_C$$

then $L_{CL} = L_C - L_{CT}$

5. A similar analysis is performed to obtain the LCO 4.1.9-2 limit, where the maximum region temperature rise is a function of core inlet temperature and core power fraction. For this analysis, initially a high value of region temperature rise is taken and then calculations are repeated with decreasing region temperature rises until the condition producing $d\Delta p/dm = 0$ is found. The critical channel for this limit is the highest power channel in the lowest power region (because the orifices are adjusted per the region power to produce equal region exit temperatures, and laminar flow instability is more sensitive to flow than to power). For this limit, the channel pressure drop is calculated using an average power channel in the region, and then flow in the high power channel in the region is obtained by solving the pressure drop equation iteratively with this pressure drop.

The data input that were used in the analysis are:

L_{UR} = 46.8 in.

L_C = 187.3 in.

L_{LR} = 46.8 in.

d = 0.625 in.

K_{in} = 0.5

K_{out} = 0.5

K_{orif} = 36.12 (7-column region, 20% open)

$f = f_o N_{RE}^{-b}$

	Laminar	Turbulent
where f_o	16	0.0195
b	1	0.0985

$N_{RE} = \frac{4\omega}{\pi d \mu}$

$\mu = \mu_o T^m$

where μ_o = 0.00069 lbm/hr-ft

m = 0.674

N_{RE}(tran) = 2300

ρ = 0.229 lbm/ft³ (107.5% of nominal)
RPF = region power density peaking factor
TILT = intra-region maximum column power tilt

	Fig. 1 Limit	Fig. 2 Limit
where RPF	3.0	0.4
TILT	1.61	1.61

As mentioned above the analysis considered a range of inlet temperatures from 100°F to 750°F. Calculations were made at 50°F increments within this range. The core power fraction was incremented by 0.002 (0.2%) of full core power. The analyses was continued until a core power to flow ratio of 1.05 was reached. In the iteration process to find the minimum core pressure drop, the

circulator flow was incremented by 0.0001 (0.01%) of 100% circulator flow (for the Figure 1 limit) and the region temperature rise was incremented by 1°F (for the Figure 2 limit).

Figures 6 through 8 show the channel pressure drop vs. flow curves for a few power fractions. The core inlet temperature for these curves was 100°F. Figures 6 and 7 were generated for the Figure 1 limit of circulator flow vs. reactor power. The step increase in core pressure drop that is seen in the coolant channel flow range of 10-15 lbm/hr is caused by the transition from laminar to turbulent flow in the lower reflector, which causes a step increase in the friction factor. A similar step increase occurs when the flow in the upper reflector becomes turbulent. This step is very small (~0.02 psf), because the flow in the upper reflector becomes turbulent at a lower flow rate, and is not evident in these figures. The effect of these steps was disregarded when looking for a minimum core pressure drop.

Figure 8 was generated for the Figure 2 limit of region temperature rise vs. core power. These curves "sweep back" to zero flow because of the effect of temperature measurement error. As core flow is increased, region temperature rises become smaller. Eventually the temperature rise becomes equal to the potential measurement error.

The curves in Figures 1 which permit the orifices on some regions to be more open than the others were generated using methods described in References 1 and 2 (some of the factors were available from these references and taken directly). These factors are given in Table 3. An orifice setting of 8% open for 7-column regions was assumed in developing the Figure 1 curves where some orifices are more open than the uniform flow positions. The Figure 1 curves are then valid for uniform orifice settings of 8 - 20% open.

Less restrictive curves may be used in cases where the primary coolant helium inventory is less than nominal. Figures 10-15 show the Figure 1 and Figure 2 limits for inventories of 80%, 60% and 40% of nominal. These were obtained by running the LAMSTAB*RJK code at the specified core inlet helium densities.

Limits have also been generated for refueling and are shown in Figures 16-18. Primary system pressure was taken to be less than or equal to 15 psi. For refueling, two circulator flow vs. core power curves have been generated. The second curve provides a limit when the reflector and fuel elements from one region have been removed. For this condition, a flow factor was derived, wherein the total flow required is increased by a factor sufficient to offset the additional flow through the cavity created during refueling. The derviation of this flow factor is given in Appendix B.

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6. Memo: A. Shenoy to D. Alberstein, "Tracing of FSV Tech Spec LCO 4.1.9 Related Material," SP&PD:AS:161:83, November 17, 1983.

7. Memo: P. Symolon to D. Alberstein, "Independent Review of Laminar Instability Analysis Supporting FSV LCO 4.1.9," SD&PD:PS:159:83, October 4, 1983.

8. R. D. Elliott and J. F. Petersen, "An Evaluation of Possible Methods for Achieving Single-Loop Operation at Fort St. Vrain," Document No. 906377, March 25, 1982.

TABLE 1

Parameter	Nominal Value	Uncertainty
Reactor leakage flow fraction (f_{LEAK})	0.07	0.03
Core bypass flow fraction (f_{by})	0.125	0.05
Core bypass power fraction ($\dot{q}_{by}$)	0.05	Not used
Control rod flow fraction ($\dot{f}_{CR}$)	0.025	0.01
Control rod power fraction ($\dot{q}_{CR}$)	0.01	0.005
Core inlet temperature (T_{IN})	Variable	10°F
Region exit temperature (T_{OUT})	Variable	50°F

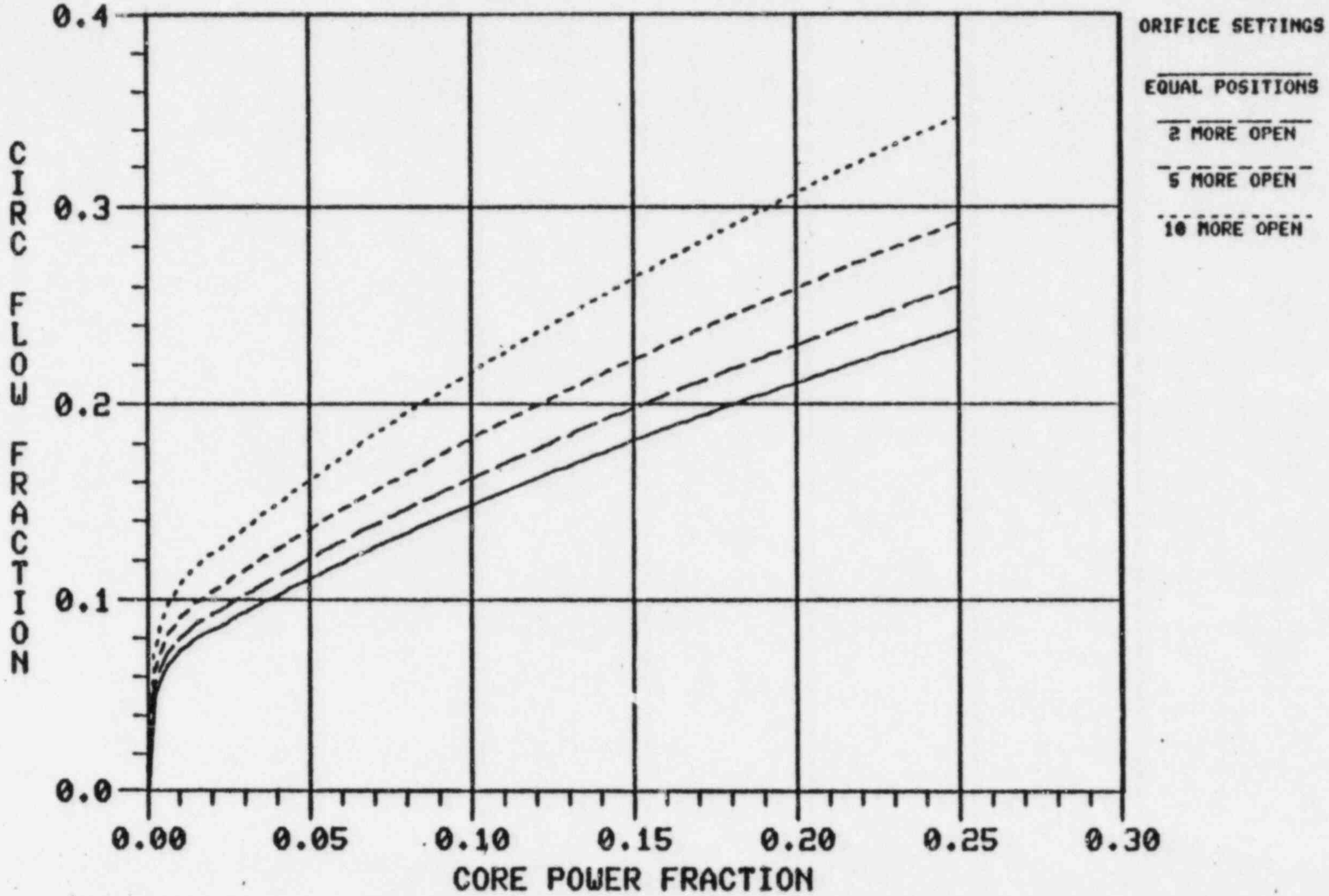
TABLE 2

Orifice Position (% open)	Core Bypass Flow Fraction
8%	0.185
13%	0.150
20%	0.125

TABLE 3

Orifice Position (% open)	Number of Orifices Opened	Required Circulator Flow Increase
8%	2	1.092
8%	5	1.279
8%	10	1.458

FIGURE 1. LCO 4.1.9-1

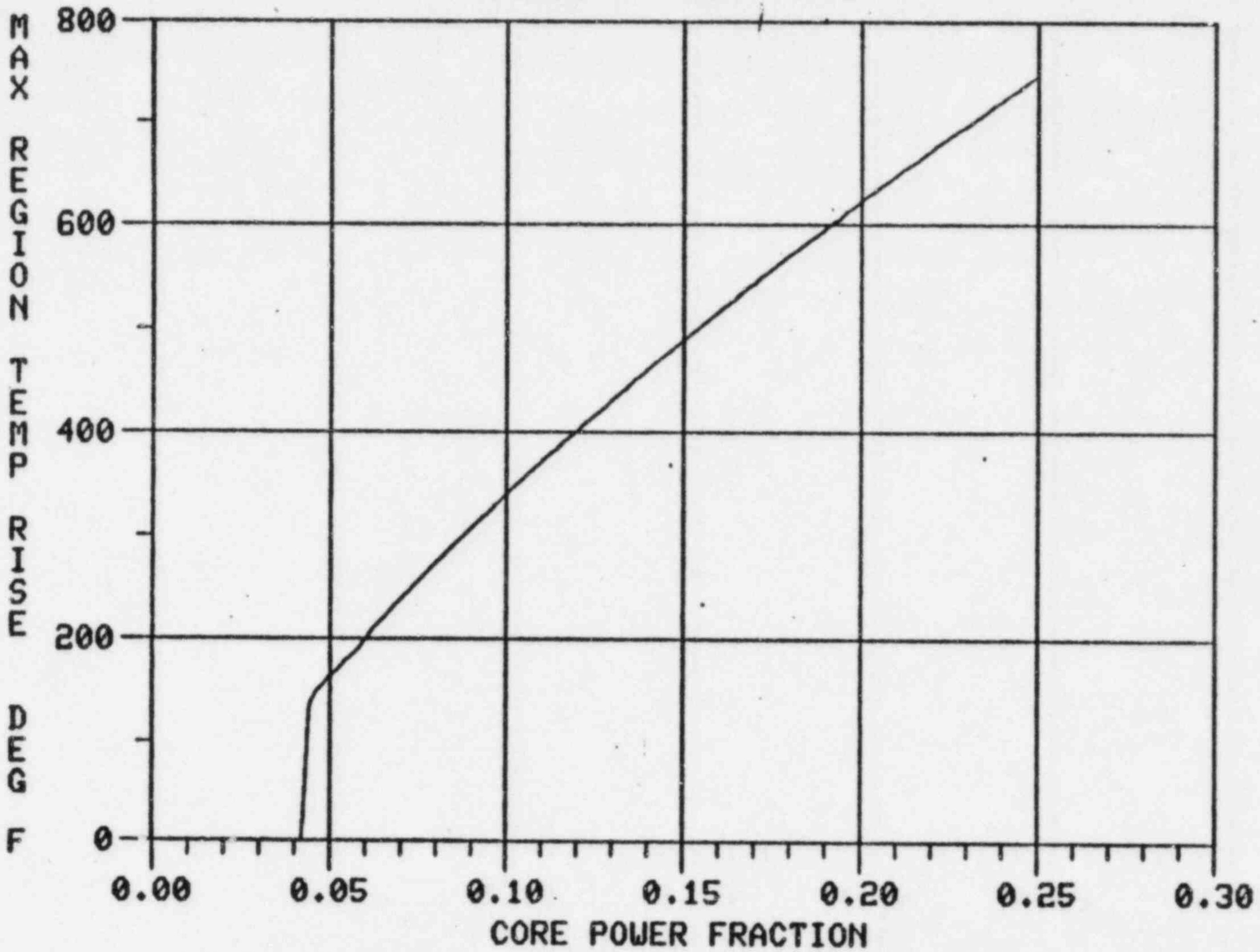


107.5% HELIUM DENSITY
ORIFICE POSITIONS OF 8%-20% OPEN

17

9072120A

FIGURE 2. LCO 4.1.9-2

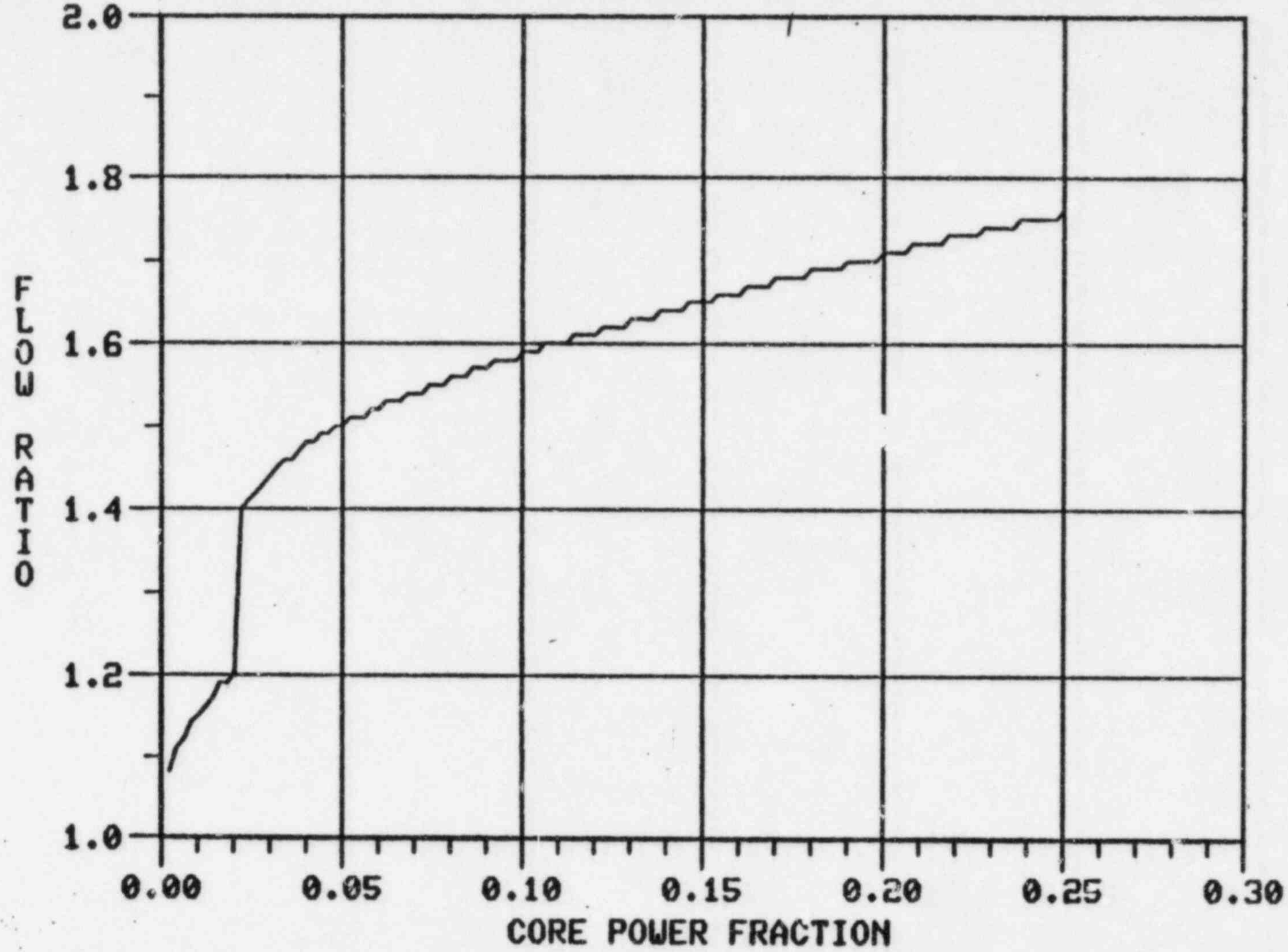


107.5% HELIUM DENSITY

9072?3/A

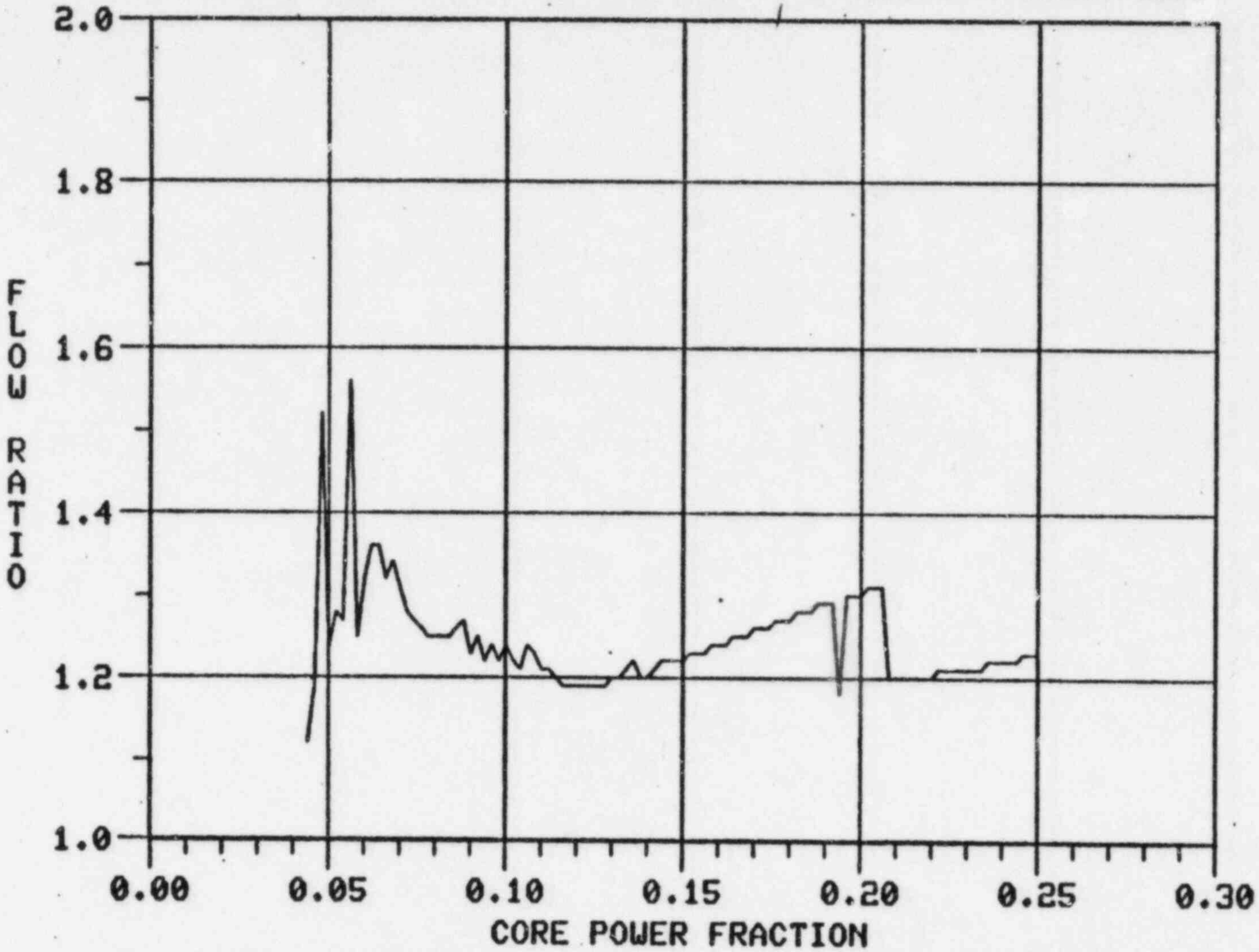
18

FIGURE 3. RATIO OF HIGH POWER AND CORE AVG CHANNEL FLOWS



107.5% HELIUM DENSITY

FIGURE 4. RATIO OF HIGH POWER AND AVG REGION CHANNEL FLOWS



107.5% HELIUM DENSITY

GA 268 (REV. 4/82)

CALCULATION SHEET

CALCULATIONS FOR			
EQUIP. NO.	PROJ.	CALC. NO.	PAGE OF
PREPARED BY	DATE	REF. DOCUMENTS: 907212/A	
CHECKED BY	DATE		

FIGURE 5 - CORE FLOW DIAGRAM

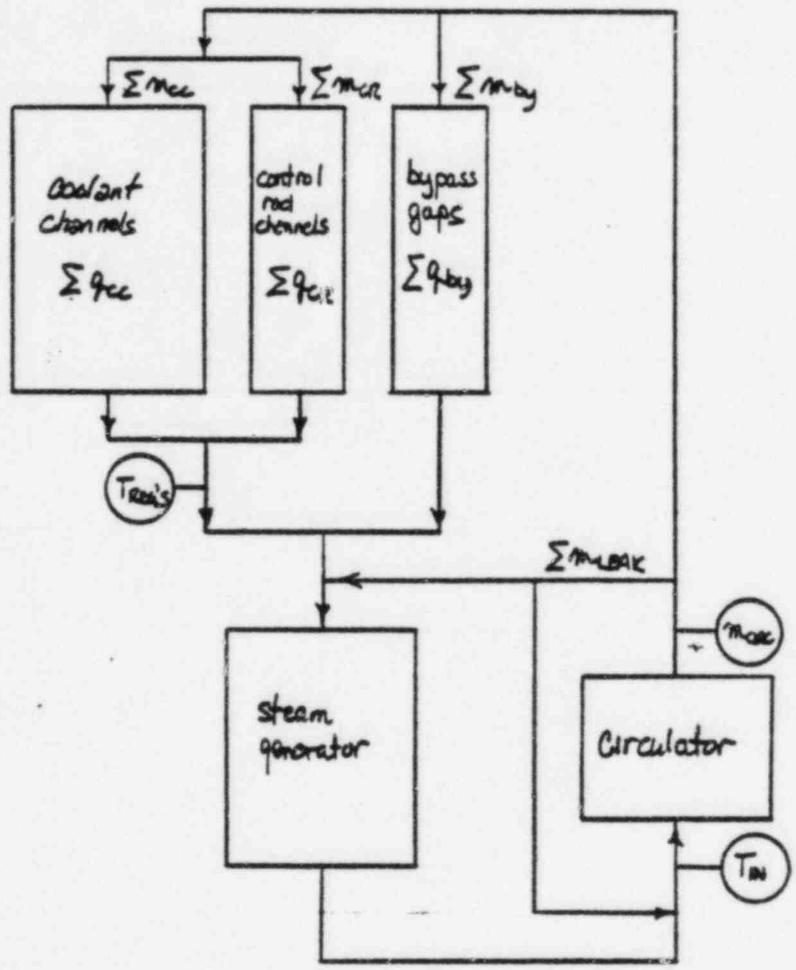


FIGURE 6. LCO 4.1.9-1 (EFFECT OF ORIFICE SETTINGS)

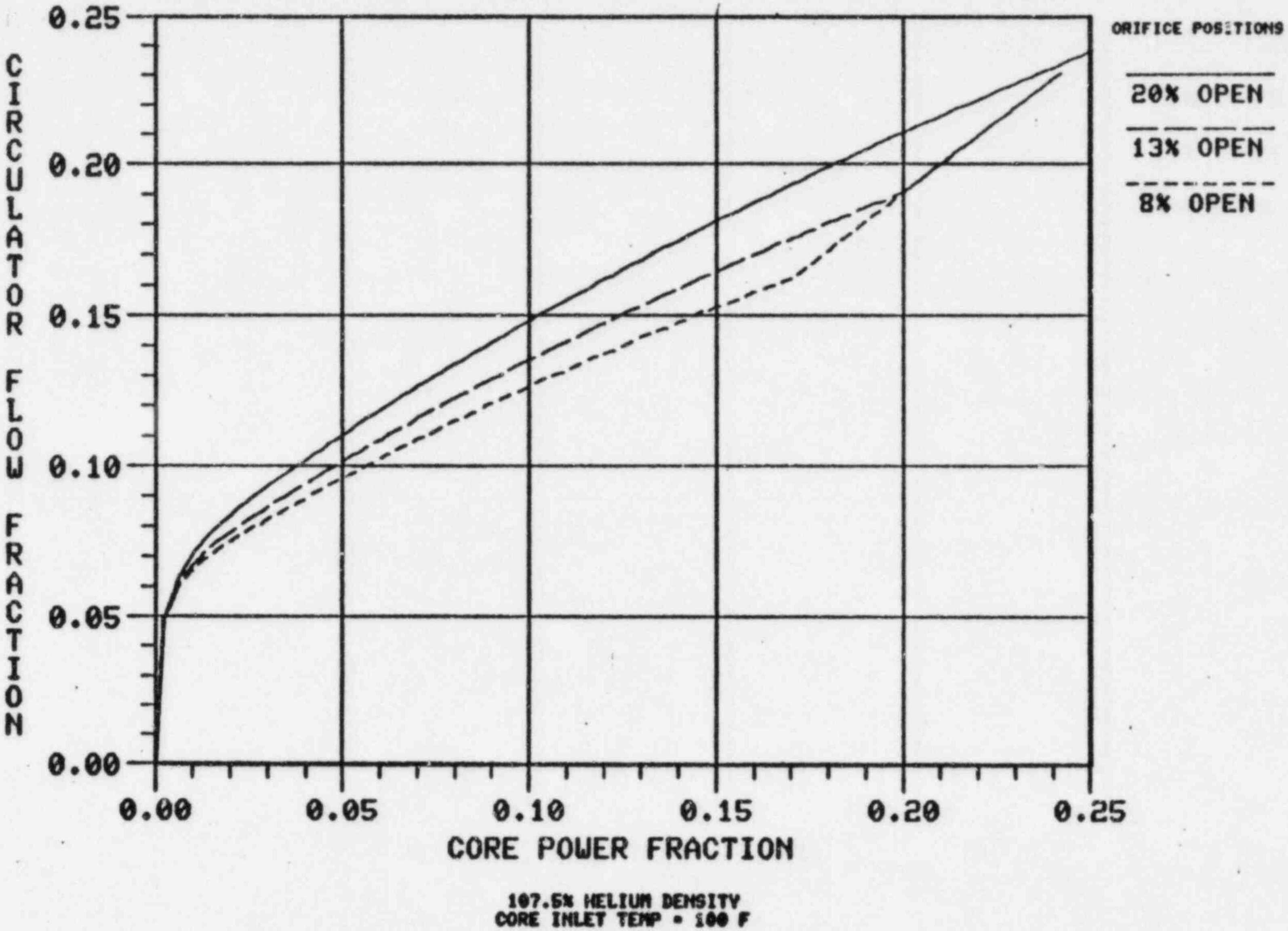
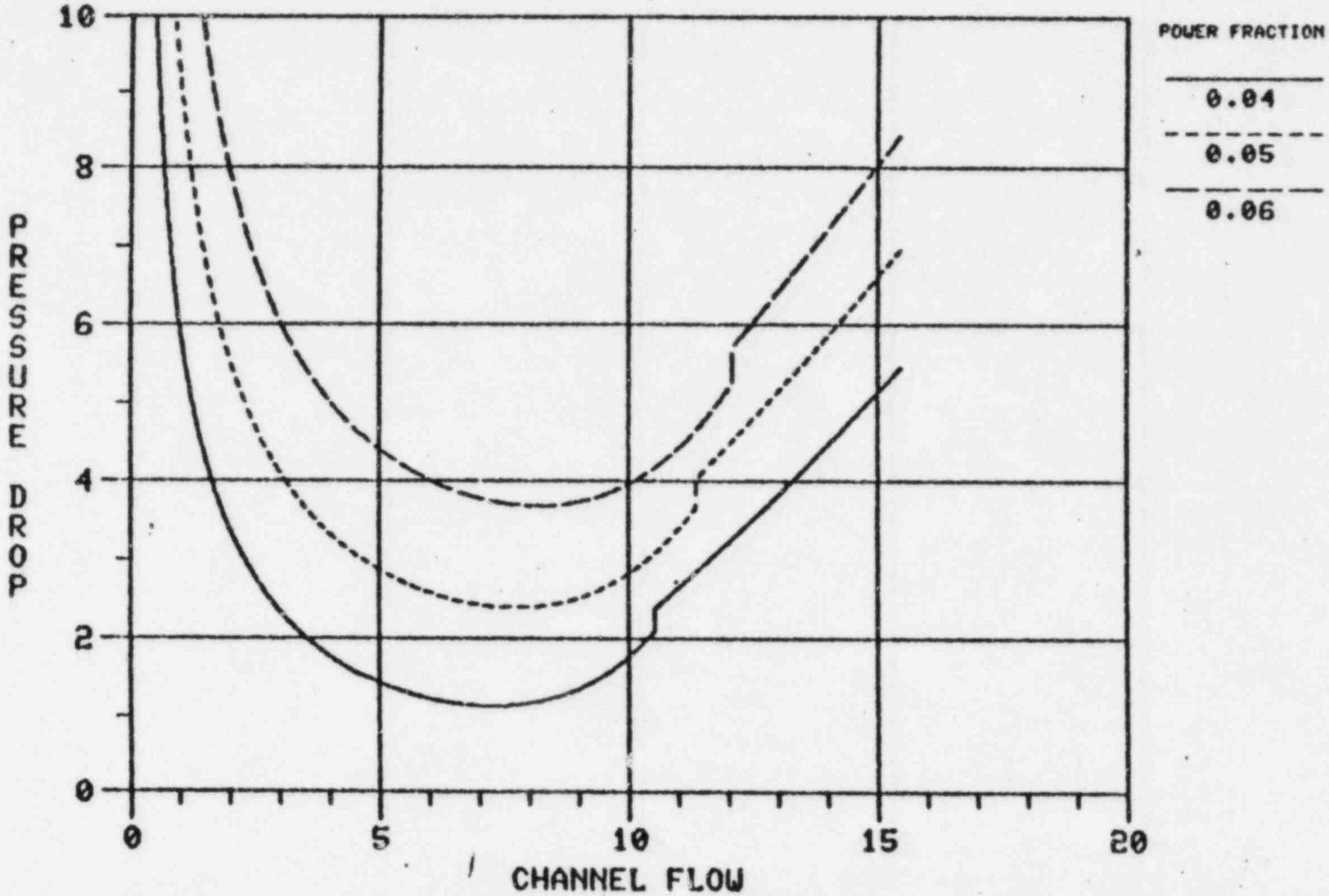


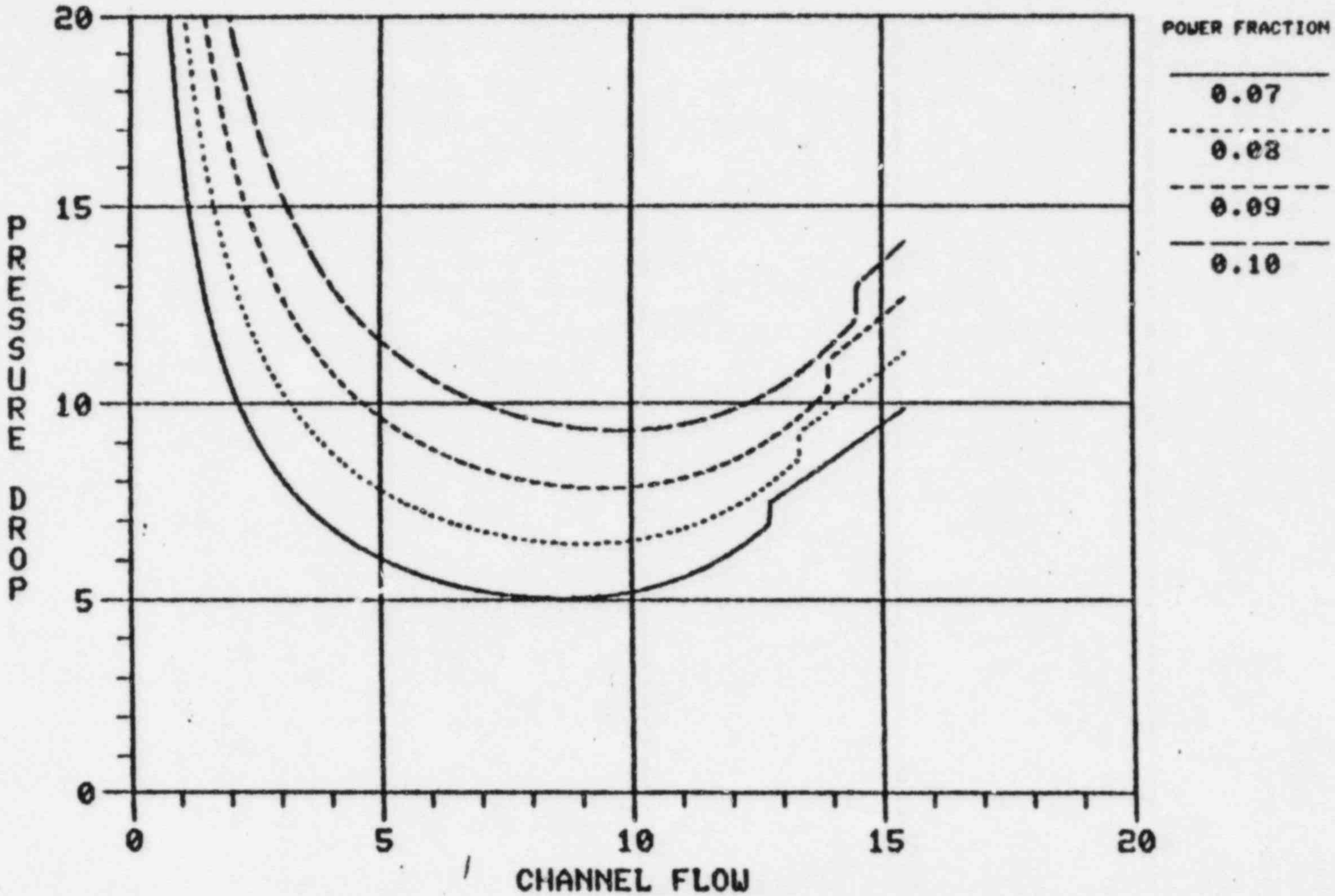
FIGURE 7. CHANNEL ΔP vs. FLOW LCO 4.1.9-1



107.5% Helium Density
Core Inlet Temp = 100°F

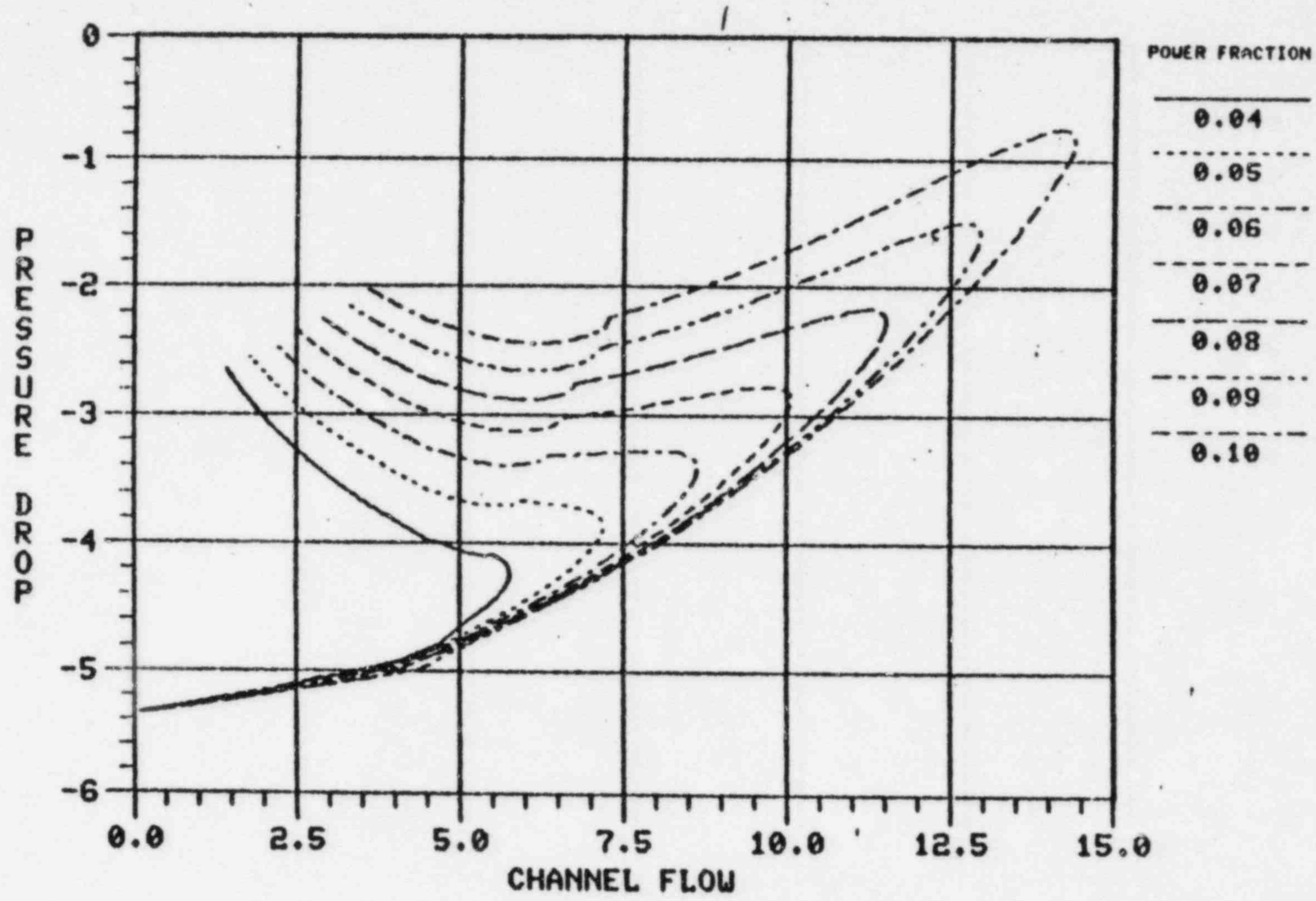
9072127A

FIGURE 8. CHANNEL ΔP vs. FLOW LCO 4.1.9-1



107.5 % HELIUM DENSITY
CORE INLET TEMP = 100°F

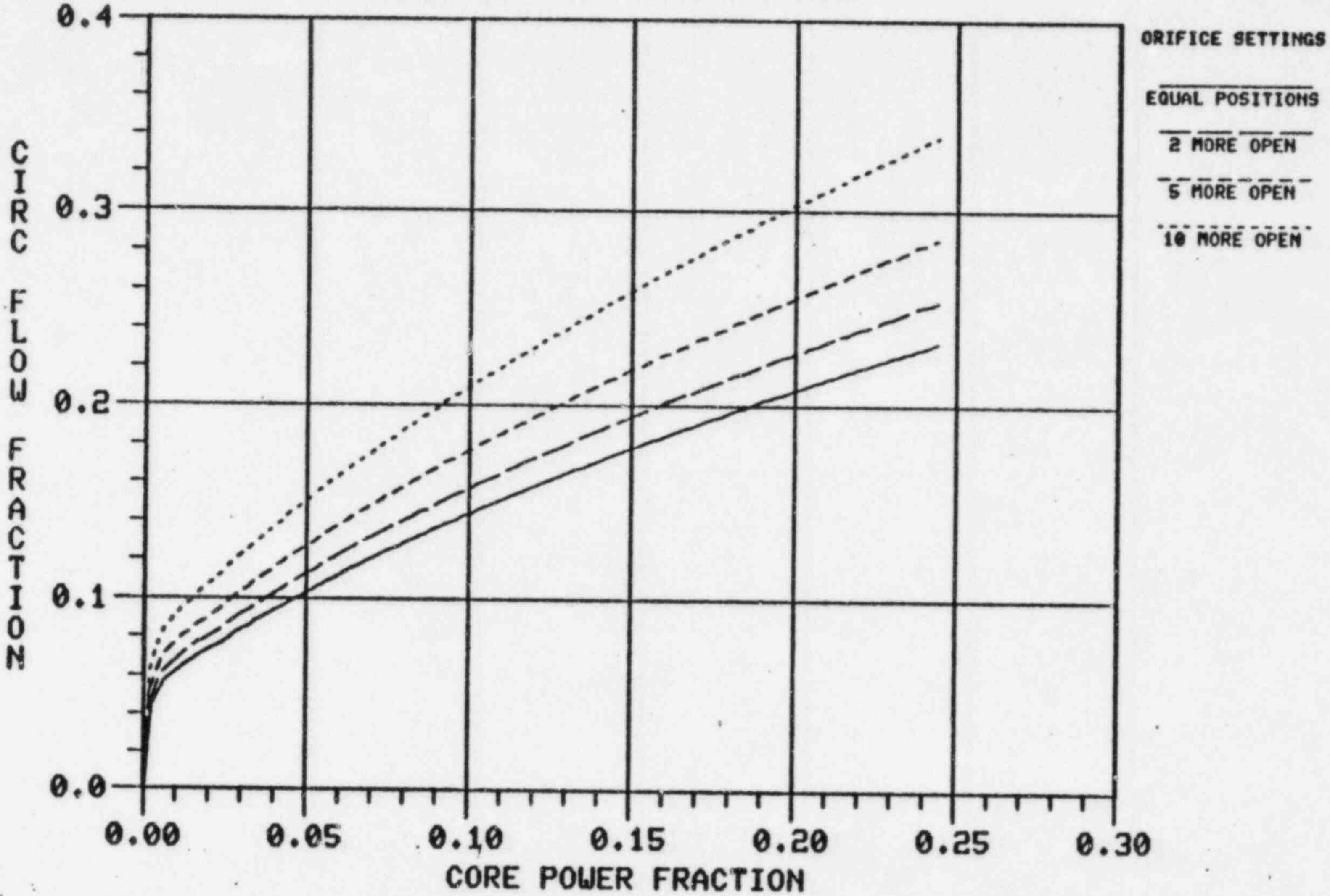
Figure 9. Channel ΔP vs Flow   LCO 4.1.9-2



107.5% Helium Dens. T
Core Inlet Temp = 100°F

907212/A

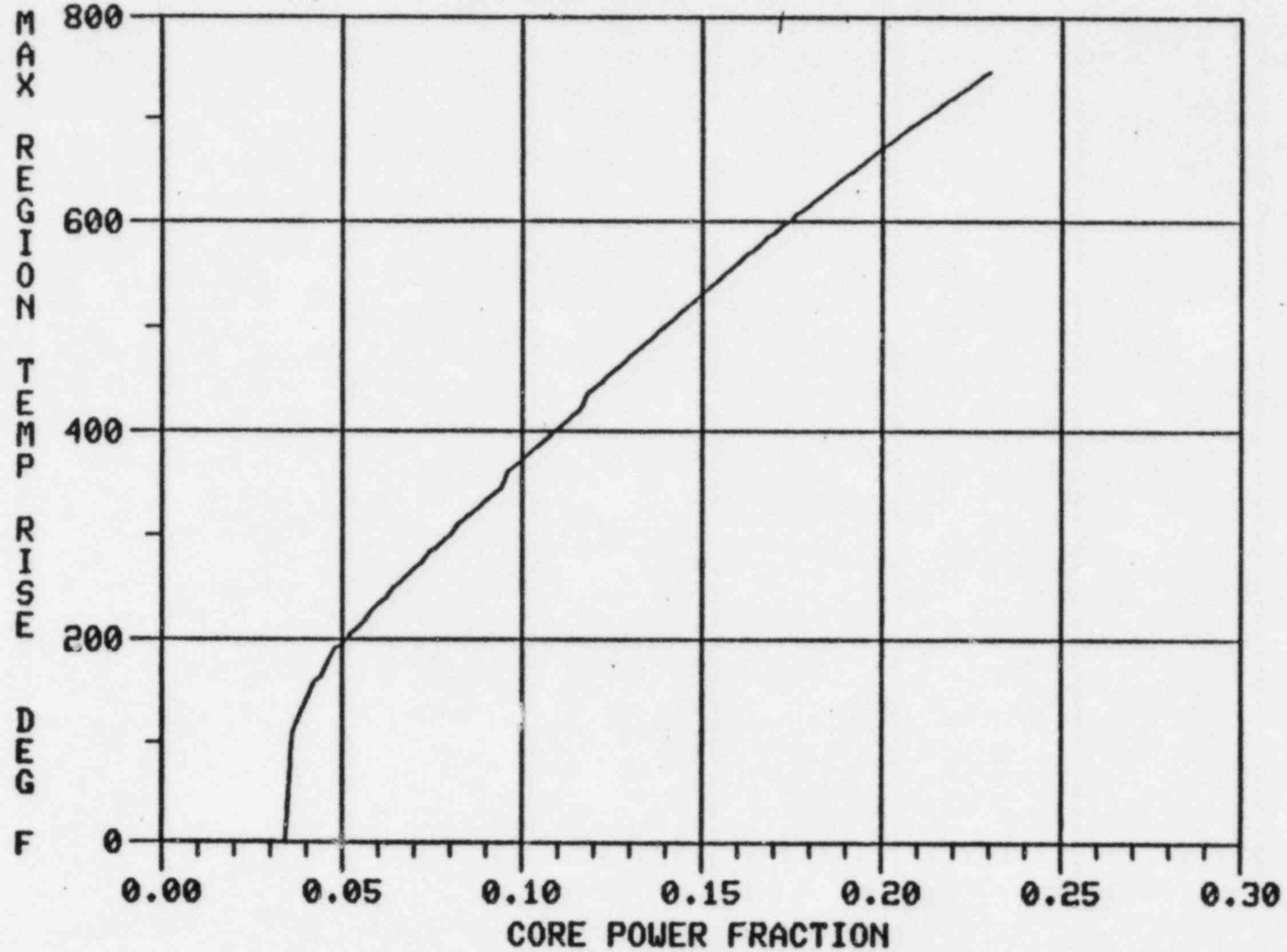
FIGURE 10. LCO 4.1.9-1



80% HELIUM DENSITY
ORIFICE POSITIONS OF 8%-20% OPEN

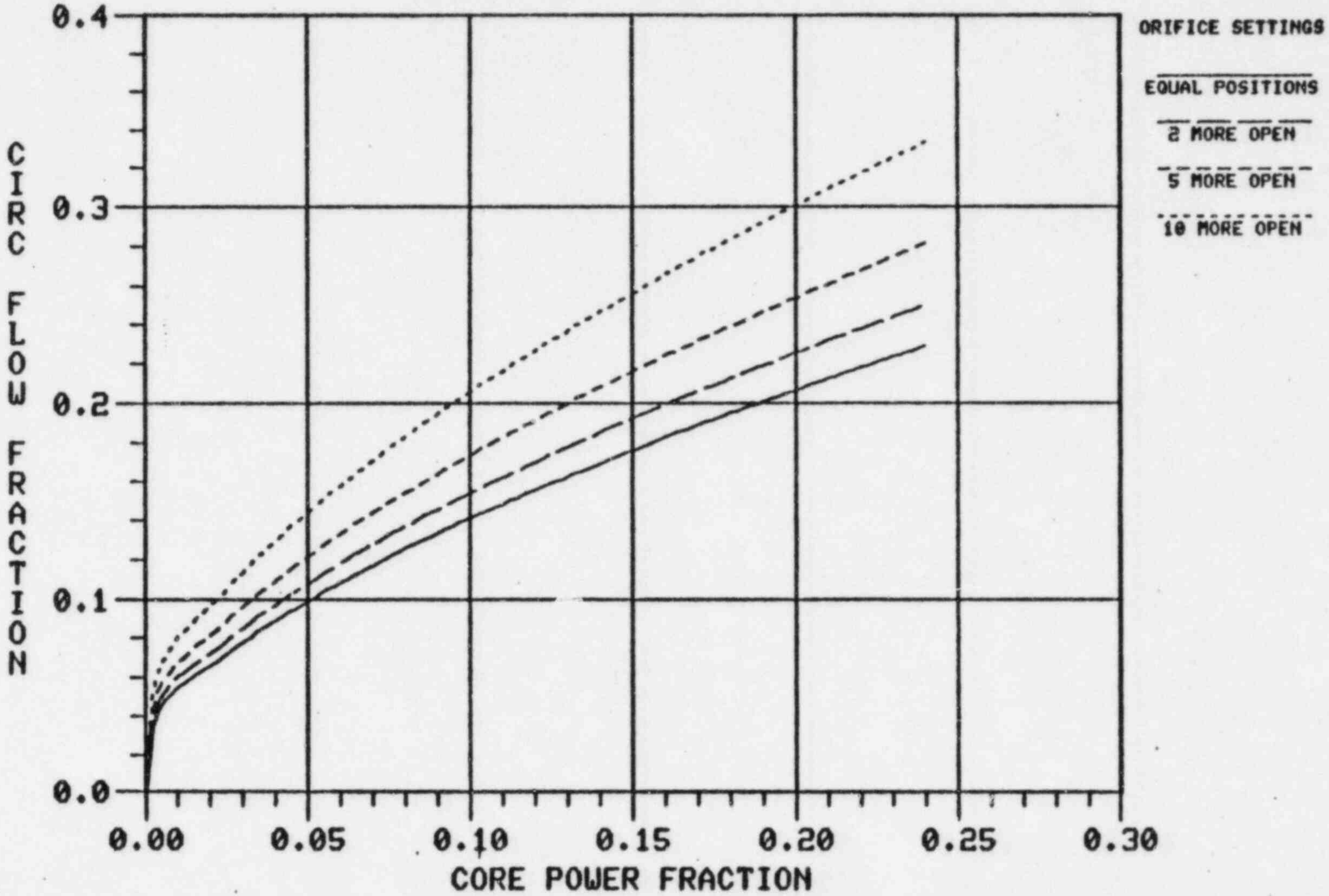
9072120A

FIGURE 11. LCO 4.1.9-2



80% HELIUM DENSITY

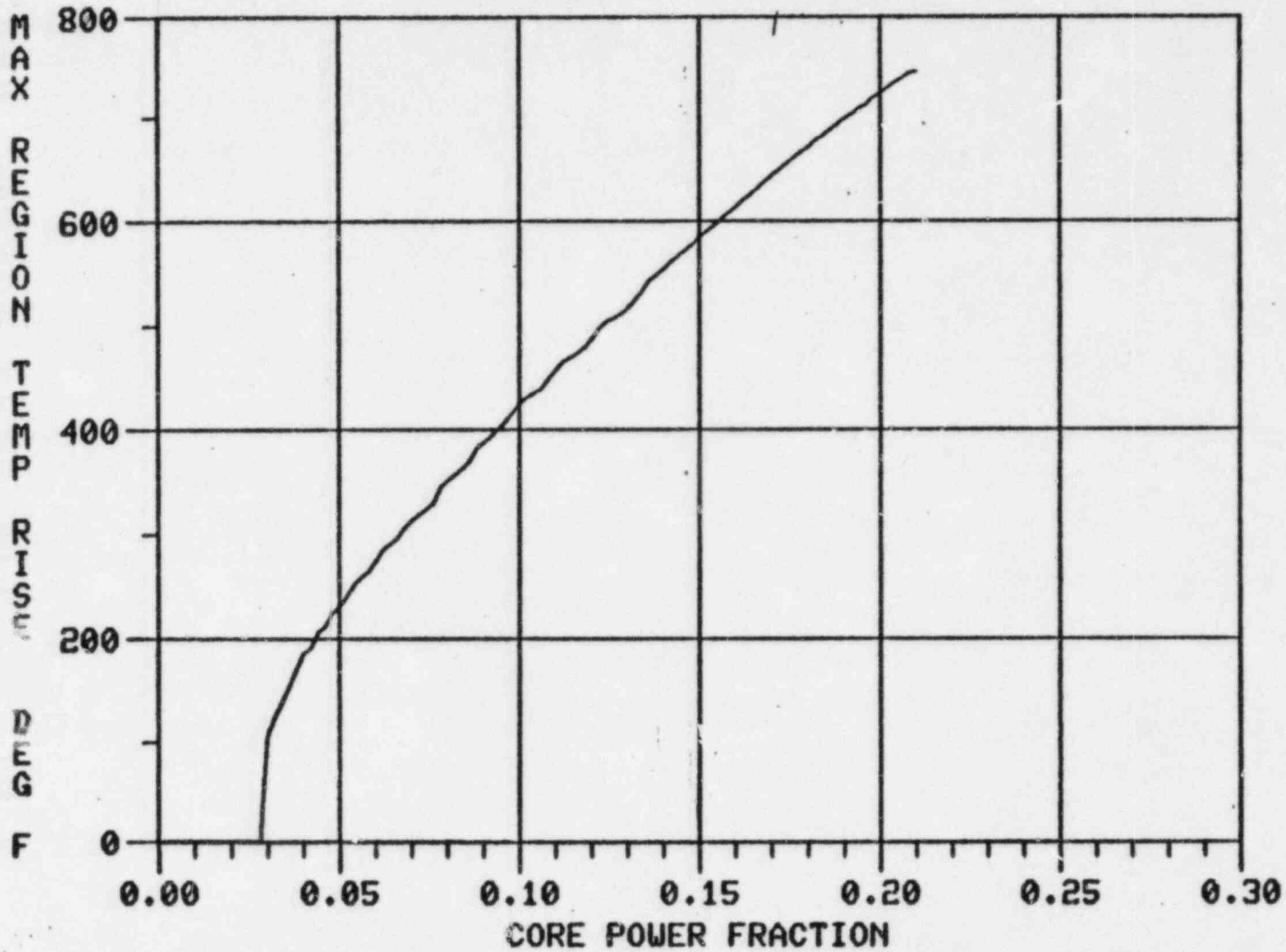
FIGURE 12. LCO 4.1.9-1



60% HELIUM DENSITY
ORIFICE POSITIONS OF 8%-20% OPEN

9072124A

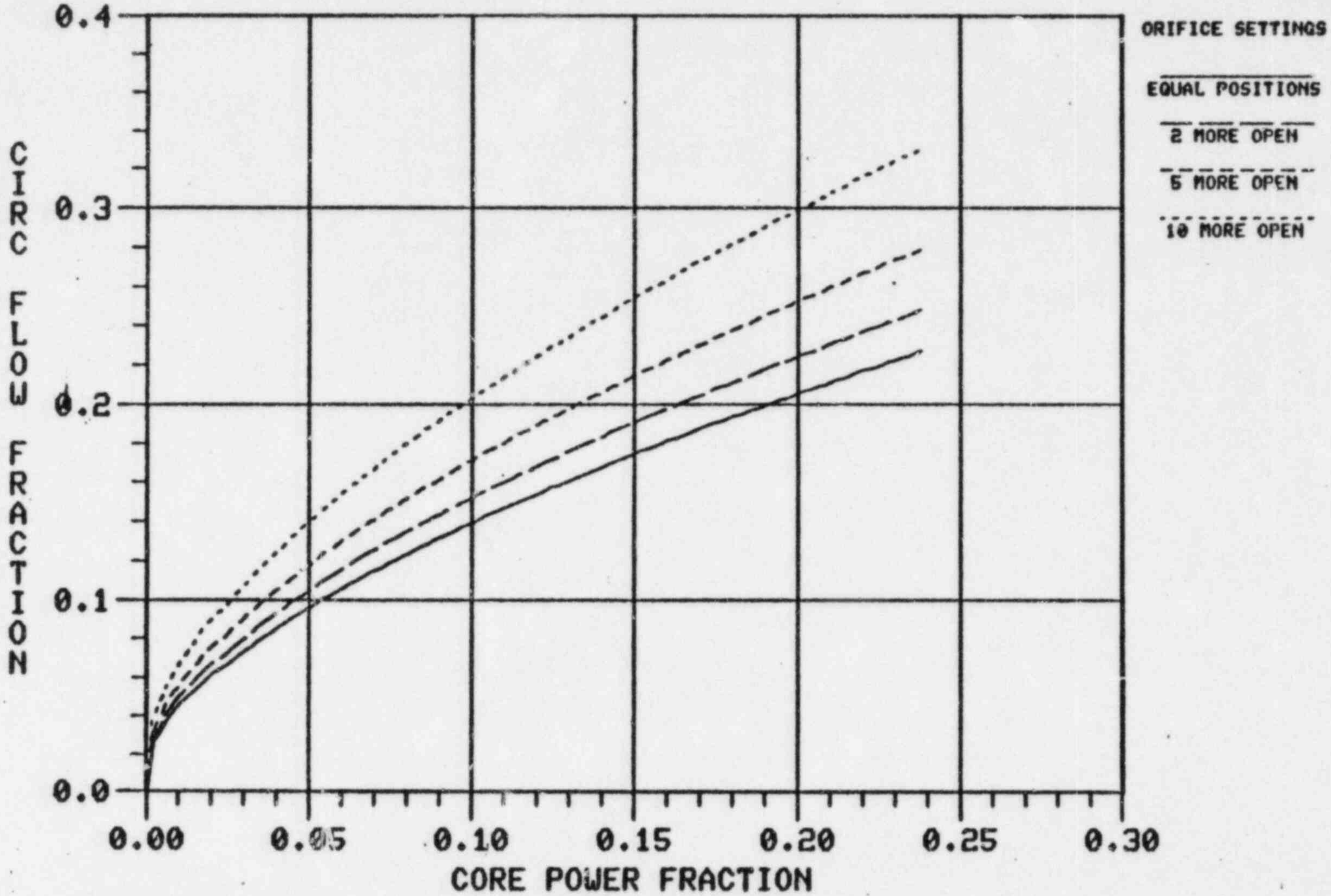
FIGURE 13. LCO 4.1.9-2



60% HELIUM DENSITY

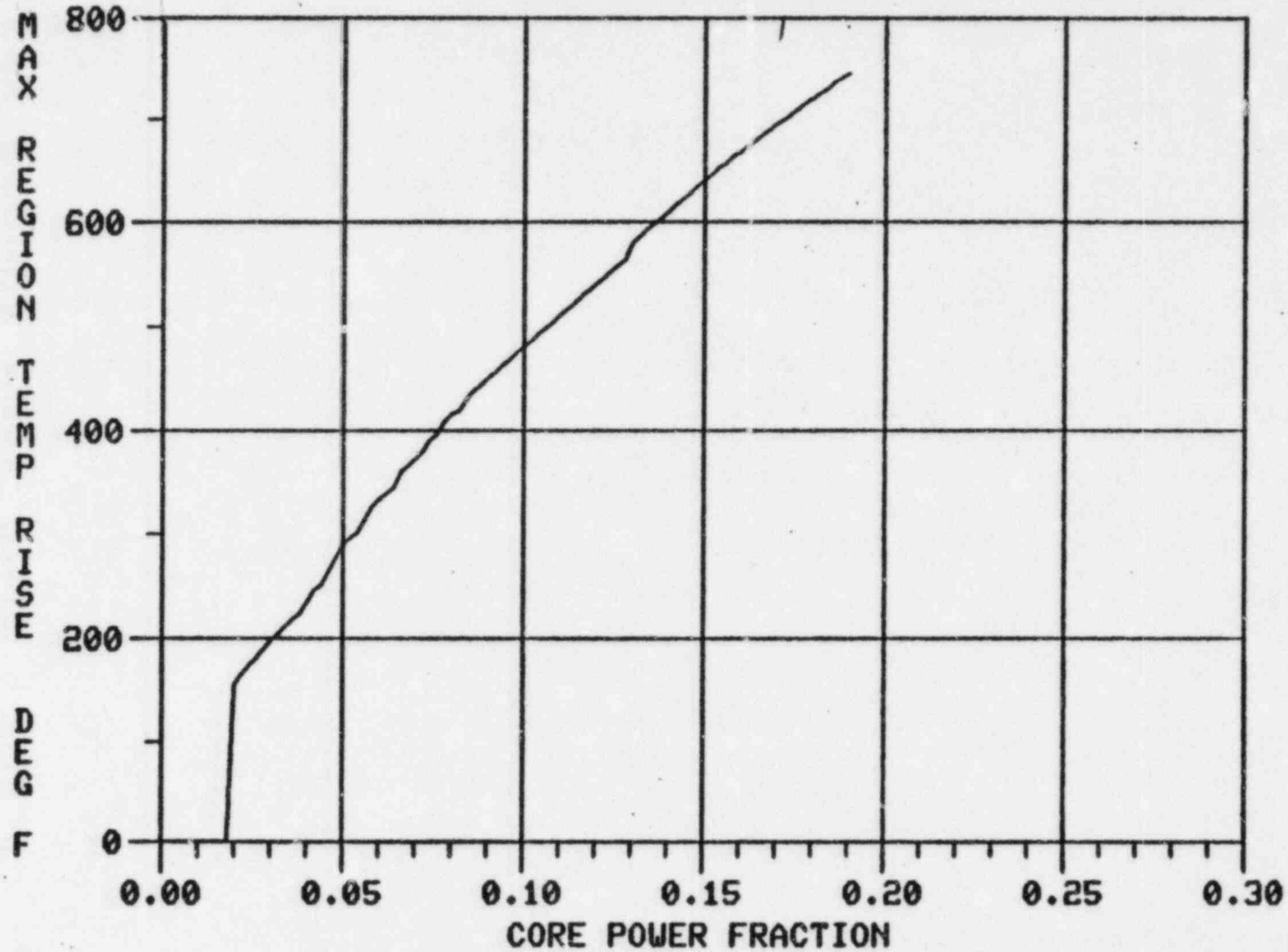
9072120/A

FIGURE 14. LCO 4.1.9-1



40% HELIUM DENSITY
ORIFICE POSITIONS OF 8%-20% OPEN

FIGURE 15. LCO 4.1.9-2

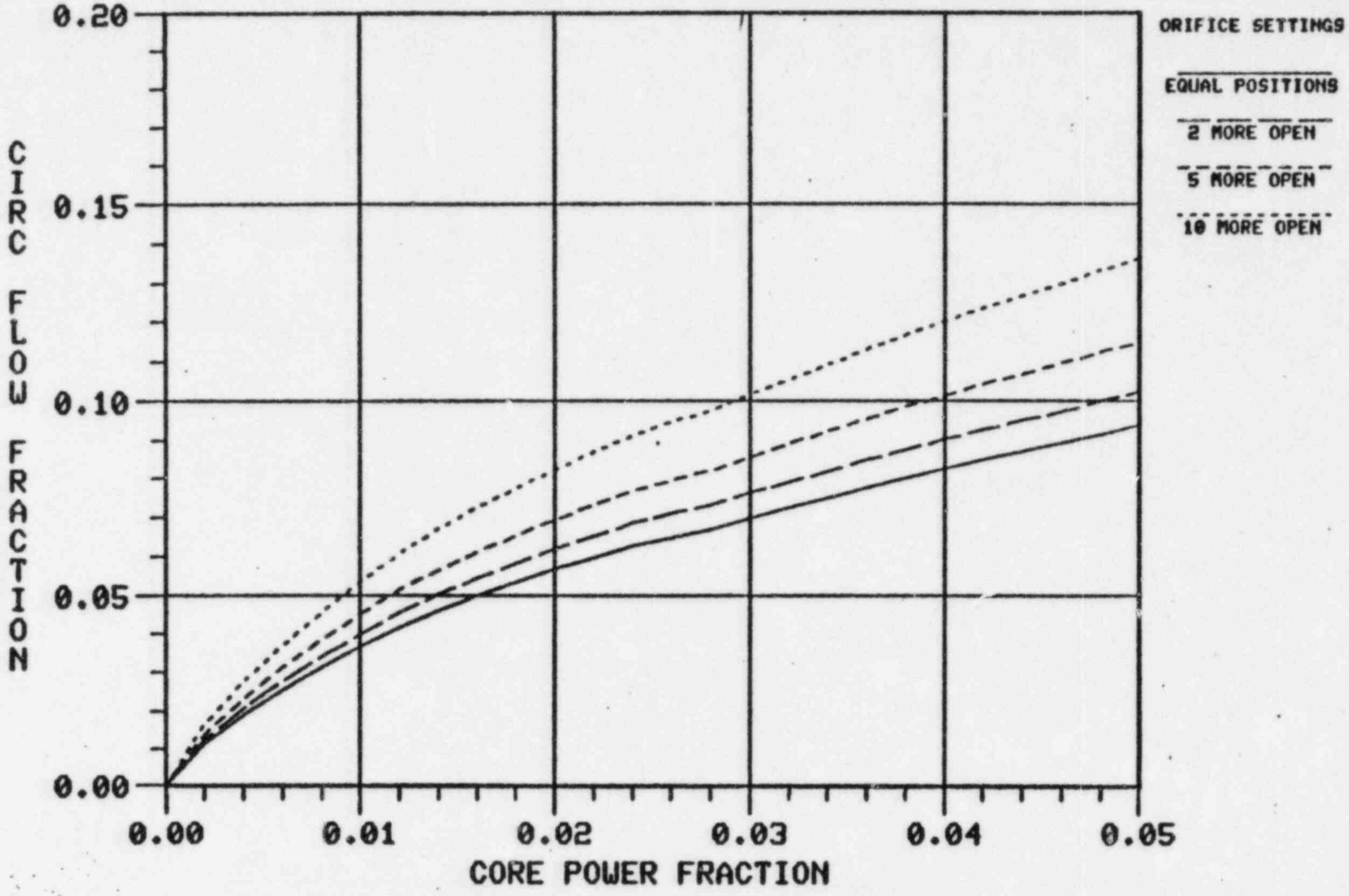


40% HELIUM DENSITY

907212/A

31

FIGURE 16. LCO 4.1.9-1 (REFUELING, ALL REGIONS IN)

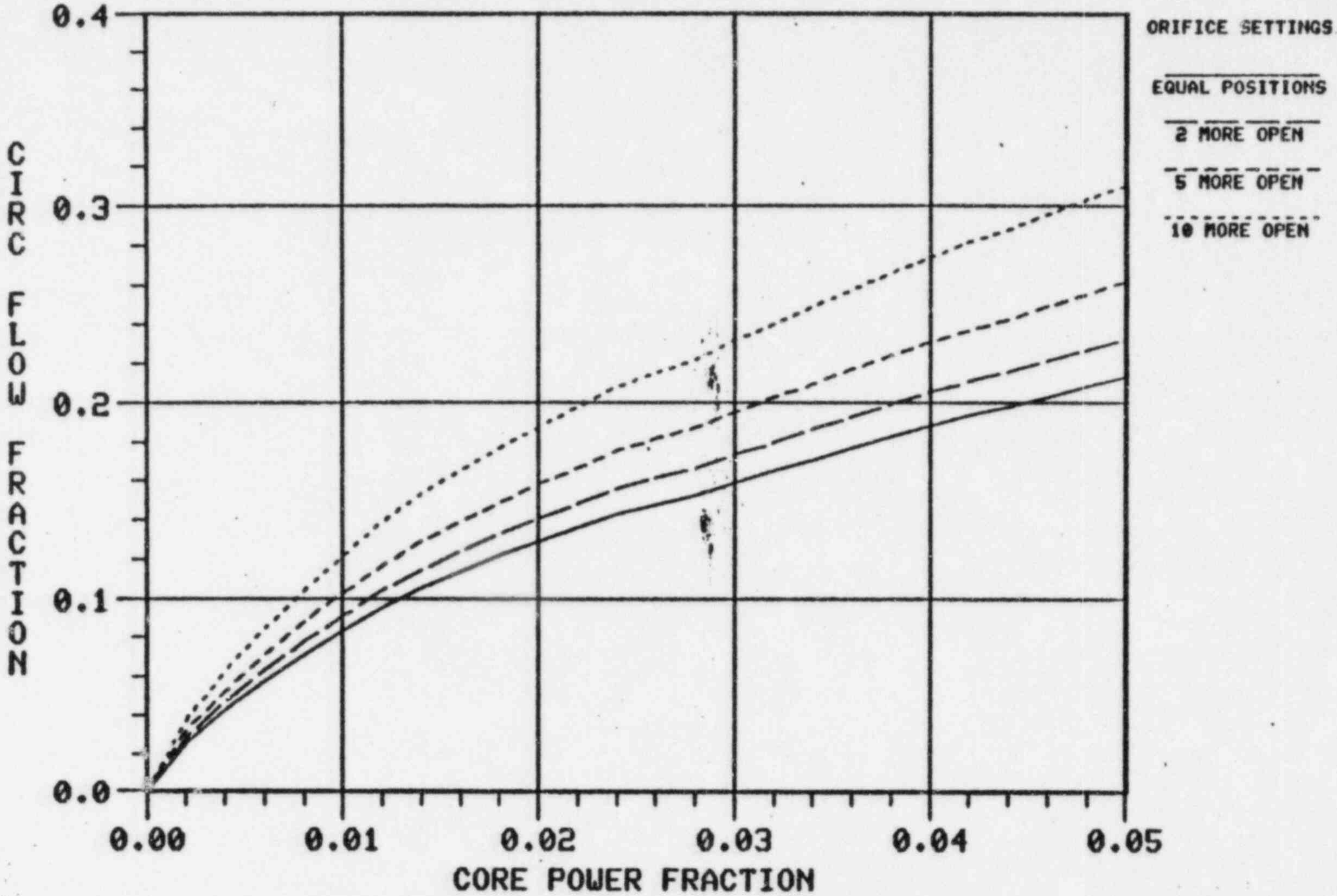


PRIMARY SYSTEM PRESSURE < 15 PSI
ORIFICE POSITIONS OF 8%-20% OPEN

32

9072124

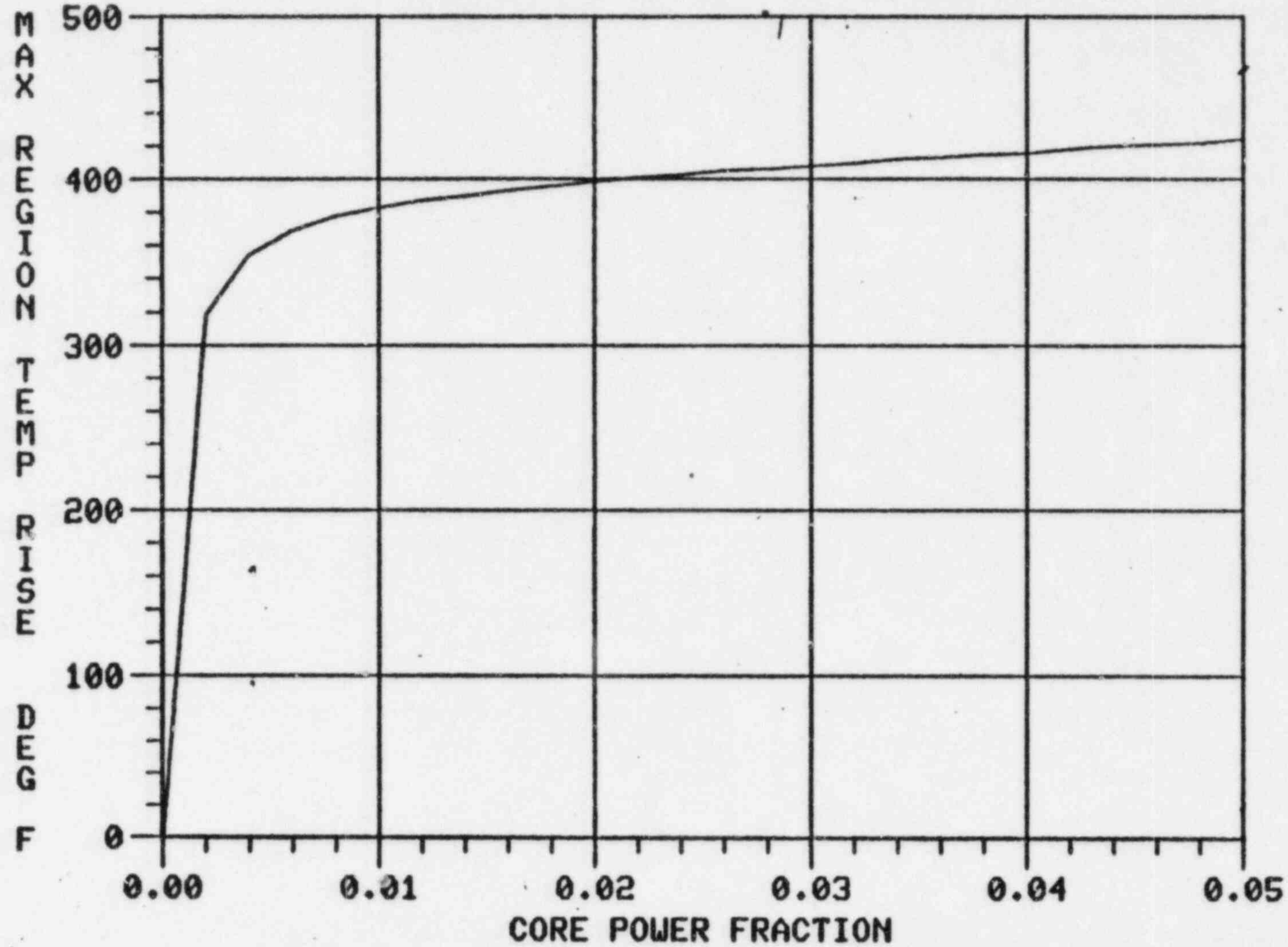
FIGURE 17 . LCO 4.1.9-1 (REFUELING, ONE REGION REMOVED)



PRIMARY SYSTEM PRESSURE < 15 PSI
ORIFICE POSITIONS OF 8%-20% OPEN

9072?2/A

FIGURE 18. LCO 4.1.9-2 (REFUELING)



PRIMARY SYSTEM PRESSURE < 15 PSI

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Appendix A

(1) For LCO 4.1.9-1 the relationship between coolant channel flow and circulator flow is needed. From the flow diagram, Figure 5:

$$m_{circ} = \Sigma m_{cc} + \Sigma m_{by} + \Sigma m_{ce} + \Sigma m_{LEAK}$$

by definition:

$$f_{LEAK} \triangleq \frac{\Sigma m_{LEAK}}{m_{circ}}$$

$$f_{by} \triangleq \frac{\Sigma m_{by}}{\Sigma m_{cc} + \Sigma m_{by} + \Sigma m_{ce}}$$

$$f_{ce} \triangleq \frac{\Sigma m_{ce}}{\Sigma m_{cc} + \Sigma m_{ce}}$$

substituting and solving for Σm_{cc}:

$$\Sigma m_{cc} = m_{circ}(1 - f_{LEAK})(1 - f_{by})(1 - f_{ce})$$

the average flow in a coolant channel is:

$$\overline{m_{cc}} \triangleq \frac{\Sigma m_{cc}}{N_{cc}}$$

where N_{cc} is the number of coolant channels in the core

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The high power channel flow is related to the average power coolant channel by:

$$\dot{m}_{cc} = \bar{\dot{m}}_{cc} / F_1$$

where F_1 is a flow defect factor

Substituting and solving for $\dot{m}_{cc}$:

$$\dot{m}_{cc} = \frac{\dot{m}_{circ}(1-f_{leak})(1-f_{by})(1-f_{cr})}{N_{cc}\ F_1}$$

Evaluating the uncertainty in $\dot{m}_{cc}$:

PARAMETER	$\frac{\partial \dot{m}_{cc}}{\partial \text{PARAMETER}} \frac{1}{\dot{m}_{cc}}$	NOMINAL VALUE OF PARAMETER	UNCERTAINTY IN PARAMETER	UNCERTAINTY IN $\dot{m}_{cc}$
$\dot{m}_{circ}$	$\frac{1}{\dot{m}_{circ}}$	—	$.05\ \dot{m}_{circ}$	.05
f_{leak}	$\frac{1}{1-f_{leak}}$	.07	.03	.03226
f_{by}	$\frac{1}{1-f_{by}}$	.125	.05	.05714
f_{cr}	$\frac{1}{1-f_{cr}}$	.025	.01	.01026

Taking the RMS of the uncertainties gives a value of:

$$\frac{d\dot{m}_{cc}}{\dot{m}_{cc}} = 0.0831$$

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Evaluating the expression for m_{cc} for the LAMSTAB code, m_{circ} is replaced by M_{FRAC}, the fraction of 100% circulator flow:

$$m_{circ}(100\%) = 3.49\ 10^6 \text{ lbm/hr}$$

also

$$N_{cc} = (102 * 210 + 52 * 37) + (6 * 210 + 5 * 37)\left(\frac{.5}{.625}\right)^{19/7}$$

$$= 24133$$

$$m_{cc} = \frac{(3.49\ 10^6)(1-.07)(1-.125)(1-.025)}{24133} \frac{M_{FRAC}}{F_1} = \frac{114.74}{F_1} M_{FRAC}$$

Note that until the pressure drop equation has been solved for both the high power and the average power channels, the ratio between their flow rates, F_1, is not known. In LAMSTAB an initial value of $F_1 = 1.0$ is assumed, then once the pressure drop equations are solved M_{FRAC} is adjusted accordingly.

To account for uncertainties, the following expression is used:

$$m_{cc} = \frac{114.74}{F_1} M_{FRAC} \left(1 - 0.0831\right)$$

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(2) In addition to the channel flow from (1), the channel coolant temperature rise may be used to establish the critical pressure drop for LCO 4.1.9-1.

From a coolant channel heat balance:

$$\Delta T_{cc} = \frac{q_{cc}}{c_p \dot{m}_{cc}}$$

From the flow diagram

$$Q_{CORE} = \Sigma q_{cc} + \Sigma q_{ce} + \Sigma q_{by}$$

where Q_{CORE} is the total core power

by definition: $$q_{by} = \frac{\Sigma q_{by}}{Q_{CORE}}$$

$$q_{ce} = \frac{\Sigma q_{ce}}{\Sigma q_{cc} + \Sigma q_{ce}}$$

substituting and solving for Σq_{cc}

$$\Sigma q_{cc} = Q_{CORE} (1 - q_{by})(1 - q_{ce})$$

the average power in a coolant channel is:

$$\overline{q_{cc}} = \frac{\Sigma q_{cc}}{N_{cc}}$$

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the high power channel is related to the average power channel by:

$$q_{cc} = \bar{q}_{cc}\ RPF\ TILT$$

where $RPF \triangleq$ region average power density peaking factor

$TILT \triangleq$ ratio of maximum column to region average power density peaking factor

substituting and solving for q_{cc}

$$q_{cc} = \frac{Q_{core}(1-q_{by})(1-q_{cc})\ RPF\ TILT}{N_{cc}}$$

Q_{core} is not a measured quantity. At low power ($< 25\%$), it is calculated from a primary side heat balance

$$Q_{CORE} = \frac{\sum m_{REG}\, c_p\, \Delta T_{REG}}{1-q_{by}} \approx \frac{c_p\, \overline{\Delta T}_{REG} \sum m_{REG}}{1-q_{by}}$$

where $\overline{\Delta T}_{REG} = \bar{T}_{REG} - T_{IN}$

from the flow diagram, Figure 5

$$\sum m_{REG} = m_{CORE}(1-f_{LEAK})(1-f_{by})$$

substituting and solving for Q_{core} :

$$Q_{CORE} = \frac{c_p(\bar{T}_{REG} - T_{IN})\, m_{CORE}(1-f_{LEAK})(1-f_{by})}{1-q_{by}}$$

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substituting and solving for q_{cc}

$$q_{cc} = \frac{c_p(\bar{T}_{REG} - T_{IN})\, m_{CIRC}\,(1-f_{LEAK})(1-f_{BY})(1-q_{cr})\, RPF\ TILT}{N_{cc}}$$

solving for ΔT_{cc} with this expression for q_{cc} and the expression for m_{cc} from (1):

$$\Delta T_{cc} = \frac{(\bar{T}_{REG} - T_{IN})\, RPF\ TILT\ F_1\,(1-q_{cr})}{1-f_{cr}}$$

Evaluating the uncertainty in ΔT_{cc}:

PARAMETER	$\frac{\partial m_{cc}}{\partial PARAMETER}\frac{1}{\Delta T_{cc}}$	NOMINAL VALUE OF PARAMETER	UNCERTAINTY IN PARAMETER	UNCERTAINTY IN ΔT_{cc}
$\bar{T}_{REG}$	$\frac{1}{\bar{T}_{REG} - T_{IN}}$	(a)	8.3°F (b)	(a)
T_{IN}	$\frac{1}{\bar{T}_{REG} - T_{IN}}$	(a)	10°F	(a)
q_{cr}	$\frac{1}{1-q_{cr}}$	.01	.005	.00505
f_{cr}	$\frac{1}{1-f_{cr}}$	.025	.01	.01026

(a) The region temperature rise depends on the conditions which produce the critical pressure drop, and is evaluated in the computer program with each iteration

(b) the uncertainty in the measured exit gas temperature is 50°F for any single region. the uncertainty in the average of the 37 regions 40

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is $50°F / \sqrt{37} = 8.3°F$.

Taking the RMS of these uncertainties gives a value of:

$$\frac{d\,\Delta T_{cc}}{\Delta T_{cc}} = \left(1.31\,10^{-4} + \frac{168.89}{(\bar{T}_{REG} - T_{IN})^2}\right)^{1/2}$$

Evaluating the expression for ΔT_{cc} and the uncertainty in ΔT_{cc} for the LAMSTAB code, $\bar{T}_{REG} - T_{IN}$ is replaced P_{FRAC} and M_{FRAC}, which are the fractions of 100% core power and circulator flow. From an expression given above:

$$\bar{T}_{REG} - T_{IN} = \frac{Q_{CORE}\,(1 - q_{by})}{C_p\, m_{circ}\,(1 - f_{REAC})(1 - f_{by})}$$

$$Q_{CORE} = P_{FRAC} * Q_{CORE}(100\%)$$

$$Q_{CORE}(100\%) = 841.7\ MW$$

$$m_{CIRC} = M_{FRAC} * m_{CIRC}(100\%)$$

$$m_{CIRC}(100\%) = 3.49\,10^{6}\ lbm/hr$$

Substituting and solving for ΔT_{cc}

$$\Delta T_{cc} = \frac{Q_{CORE}(100\%)(1 - q_{by})(1 - q_{cc})\,RPF\ TILT\ F_1}{C_p\, m_{CIRC}(100\%)(1 - f_{REAC})(1 - f_{by})(1 - f_{cc})}\ \frac{P_{FRAC}}{M_{FRAC}}$$

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$$\Delta T_{cc} = \frac{(841.7)(3.413\ 10^6)(1-.05)(1-.01)(.9358)\ F_1}{(1.242)(3.49\ 10^6)(1-.07)(1-.125)(1-.025)} \frac{P_{FRAC}}{M_{FRAC}}$$

where $3.413\ 10^6$ is a power conversion factor (MW to BTU/hr) and .9358 is a power density conversion factor (GAUGE TILT to coolant channel tilt).

$$\boxed{\Delta T_{cc} = 735.18\ F_1\ RPF\ TILT\ \frac{P_{FRAC}}{M_{FRAC}}}$$

The uncertainty expression may also be given in terms of P_{FRAC} and M_{FRAC}: Substituting for $F_{AGG} - T_{IN}$ and solving:

$$\frac{d\Delta T_{cc}}{\Delta T_{cc}} = \left(1.31\ 10^{-4} + \frac{168.89\ C_p^2\ m_{CIRC}(100\%)^2(1-f_{FRAC})^2(1-f_{by})^2}{q_{CORE}(100\%)^2(1-q_{by})^2}\left(\frac{M_{FRAC}}{P_{FRAC}}\right)^2\right)^{\frac{1}{2}}$$

$$\frac{d\Delta T_{cc}}{\Delta T_{cc}} = \left(1.31\ 10^{-4} + \frac{(168.89)(1.242)^2(3.49\ 10^6)^2(1-.07)^2(1-.125)^2}{(841.7)^2(3.413\ 10^6)^2(1-.05)^2}\left(\frac{M_{FRAC}}{P_{FRAC}}\right)^2\right)^{\frac{1}{2}}$$

$$\boxed{\frac{d\Delta T_{cc}}{\Delta T_{cc}} = \left(1.31\ 10^{-4} + 2.82\ 10^{-4}\left(\frac{M_{FRAC}}{P_{FRAC}}\right)^2\right)^{\frac{1}{2}}}$$

To account for uncertainties, the following expression is used:

$$\boxed{\Delta T_{cc} = 735.18\ F_1\ RPF\ TILT\ \frac{P_{FRAC}}{M_{FRAC}}\left[1 - \left(1.31\ 10^{-4} + 2.82\ 10^{-4}\left(\frac{M_{FRAC}}{P_{FRAC}}\right)^2\right)^{\frac{1}{2}}\right]}$$

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(3) For LCO 4.1.9-2 the relationship between coolant channel flow and region temperature rise and circulator flow is needed

From a coolant channel heat balance:

$$\dot m_{cc} = \frac{q_{cc}}{c_p \, \Delta T_{cc}}$$

An expression for q_{cc} was developed in (2):

$$q_{cc} = \frac{c_p (\bar T_{REG} - T_{IN}) \, \dot m_{circ} (1-f_{LEAK})(1-f_{BY})(1-q_{CR}) \, RPF \; TILT}{N_{cc}}$$

And the coolant temperature rise in the high power channel is related to the region average coolant temperature rise by:

$$\Delta T_{cc} = (T_{REG} - T_{IN}) \; TILT \; F_Z \left(\frac{1-q_{CR}}{1-f_{CR}} \right)$$

where F_Z is the ratio between the high power and average power channels in the region.

Substituting:

$$\dot m_{cc} = \frac{(\bar T_{REG} - T_{IN}) \, \dot m_{circ} (1-f_{LEAK})(1-f_{BY})(1-f_{CR}) \, RPF}{F_Z \, N_{cc} \, (T_{REG} - T_{IN})}$$

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Evaluating the uncertainty in $\dot{m}_{cc}$

PARAMETER	$\frac{\partial \dot{m}_{cc}}{\partial \text{PARAMETER}} \frac{1}{\dot{m}_{cc}}$	NOMINAL VALUE OF PARAMETER	UNCERTAINTY IN PARAMETER	UNCERTAINTY IN $\dot{m}_{cc}$
$\dot{m}_{CIRC}$	$\frac{1}{\dot{m}_{CIRC}}$	—	.05	.05
f_{LEAK}	$\frac{1}{1-f_{LEAK}}$	.07	.03	.03226
f_{by}	$\frac{1}{1-f_{by}}$	.125	.05	.05714
f_{CR}	$\frac{1}{1-f_{CR}}$	.025	.01	.01026
$\bar{T}_{REG}$	$\frac{r}{\bar{T}_{REG}-T_{IN}}$	—	8.3°F	—
T_{REG}	$\frac{1}{T_{REG}-T_{IN}}$	—	50°F	—
T_{IN}	$\frac{\bar{T}_{REG}-T_{REG}}{(\bar{T}_{REG}-T_{IN})(T_{REG}-T_{IN})}$	—	10°F	—

Taking the RMS of these uncertainties gives a value of:

$$\frac{\partial \dot{m}_{cc}}{\dot{m}_{cc}} = \left(6.91\ 10^{-3} + \frac{68.89}{(\bar{T}_{REG}-T_{IN})^2} + \frac{2500}{(T_{REG}-T_{IN})^2} + \frac{100(\bar{T}_{REG}-T_{REG})}{(\bar{T}_{REG}-T_{IN})(T_{REG}-T_{IN})} \right)^{1/2}$$

$\bar{T}_{REG}$ is unknown in this expression. The most restrictive region, however, is the low power region, and because of the limited flow control range of the orifice, the temperature rise in this region can never be greater than $\overline{\Delta T}_{REG}$. Assuming this region is controlling and $\Delta T_{REG} = \overline{\Delta T}_{REG}$:

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$$\boxed{\frac{d\,m_{cc}}{m_{cc}} = \left(6.91\,10^{-3} + \frac{2568.89}{(T_{REG}-T_{IN})^2}\right)^{1/2}}$$

Evaluating the expression for m_{cc} for the LAMSTAB code, $(T_{REG}-T_{IN})$ and m_{CORE} are replaced by P_{FRAC}:

$$Q_{CORE} = \frac{m_{CORE}\,c_p\,(T_{REG}-T_{IN})(1-f_{brac})(1-f_{by})}{(1-q_{by})}$$

$$P_{FRAC} = \frac{Q_{CORE}}{Q_{CORE}(100\%)}$$

Substituting and solving for m_{cc}

$$m_{cc} = \frac{Q_{CORE}(100\%)(1-q_{by})(1-f_{cc})\,RPF}{N_{cc}\,c_p\,F_Z}\;\frac{P_{FRAC}}{(T_{REG}-T_{IN})}$$

$$m_{cc} = \frac{(841.7)(3.413\,10^{6})(1-.05)(1-.025)}{(24133)(1.242)}\;\frac{RPF\,P_{FRAC}}{F_Z\,(T_{REG}-T_{IN})}$$

$$\boxed{m_{cc} = 88775\,\frac{RPF\,P_{FRAC}}{F_Z\,(T_{REG}-T_{IN})}}$$

To account for uncertainties, in LAMSTAB + RTK:

$$\boxed{m_{cc} = 88775\,\frac{RPF\,P_{FRAC}}{F_Z\,(T_{REG}-T_{IN})}\left(1-\left(6.91\,10^{-3}+\frac{2568.89}{(T_{REG}-T_{IN})^2}\right)^{1/2}\right)}$$

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(4) In addition to the channel flow from (3), the channel coolant temperature rise may be used to establish the critical pressure drop for LCO 4.1.9-2.

From a coolant channel heat balance:

$$\Delta T_{cc} = \frac{q_{cc}}{c_p m_{cc}}$$

by definition: $m_{cc} = \frac{\bar{m}_{cc}}{F_z}$

where $\bar{m}_{cc}$ is the average coolant channel flow in the region

F_z is the ratio of the average to peak power channel flows in the region

the total region flow is:

$$m_{reg} = N_{reg}\,\bar{m}_{cc} + m_{cR} = \frac{N_{reg}\,\bar{m}_{cc}}{1 - f_{cR}}$$

where N_{reg} is the number of coolant holes in the region

Substituting and solving for m_{cc}

$$m_{cc} = \frac{m_{reg}(1 - f_{cR})}{F_z N_{reg}}$$

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Similarly for q_{cc}:

$$q_{cc} = \bar{q}_{cc} \, TILT$$

where $\bar{q}_{cc}$ is the region average coolant channel power

$$q_{reg} = N_{REG} \bar{q}_{cc} + q_{cr} = \frac{N_{REG} \bar{q}_{cc}}{1 - q_{cr}}$$

Solving for q_{cc}:

$$q_{cc} = \frac{q_{reg} \, TILT \, (1 - q_{cr})}{N_{reg}}$$

Substituting and solving for ΔT_{cc}:

$$\boxed{\Delta T_{cc} = \Delta T_{REG} \, TILT \, F_z \left(\frac{1 - q_{cr}}{1 - f_{cr}} \right)}$$

where $\Delta T_{REG} = \dfrac{q_{reg}}{c_p \, m_{reg}}$

Solving for ΔT_{cc}:

$$\Delta T_{cc} = (0.9358) \left(\frac{1 - .01}{1 - .025} \right) F_z \, TILT \, \Delta T_{REG}$$

$$\boxed{\Delta T_{cc} = .9502 \, F_z \, TILT \, \Delta T_{REG}}$$

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Evaluating the uncertainty in ΔT_{cc}:

PARAMETER	$\frac{d\,\Delta T_{cc}}{d\,\text{PARAMETER}} \frac{1}{\Delta T_{cc}}$	NOMINAL VALUE OF PARAMETER	UNCERTAINTY IN PARAMETER	UNCERTAINTY IN ΔT_{cc}
T_{REG}	$\frac{1}{T_{REG} - T_{IN}}$	–	50°F	–
T_{IN}	$\frac{1}{T_{REG} - T_{IN}}$	–	10°F	–
q_{CR}	$\frac{1}{1 - q_{CR}}$	.01	.005	.00505
f_{CR}	$\frac{1}{1 - f_{CR}}$	.025	.01	.01026

Taking the RMS of these terms:

$$\frac{d\,\Delta T_{cc}}{\Delta T_{cc}} = \left(1.31\ 10^{-4} + \frac{2600}{\Delta T_{REG}^2}\right)^{1/2}$$

To account for uncertainties, the following expression is used for ΔT_{cc}

$$\Delta T_{cc} = .9502\ F_Z\ \text{TILT}\ \Delta T_{REG}\left[1 - \left(1.31\ 10^{-4} + \frac{2600}{\Delta T_{REG}^2}\right)^{1/2}\right]$$

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APPENDIX B

During refueling the reflector and fuel blocks in one region may be removed, down to the core support floor. In this situation, the circulator flow must be increased to offset the increased flow through this space, such that the flow in the other 36 regions is the same as what it was before the region was removed.

The flow increase required may be expressed as:

$$\text{Flow Increase} = \frac{(5+m_r)N_5 + 31N_7}{6N_5 + 31N_7} \quad \text{(see Ref. 2)}$$

where: N_5 is the number of coolant holes in a 5 column region

$$N_5 = (4 \cdot 102 + 52) + (4 \cdot 6 + 5)\left(\frac{.5}{.625}\right)^{19/7} = 475.83$$

N_7 is the number of coolant holes in a 7 column region

$$N_7 = (6 \cdot 102 + 52) + (6 \cdot 6 + 5)\left(\frac{.5}{.625}\right)^{19/7} = 686.37$$

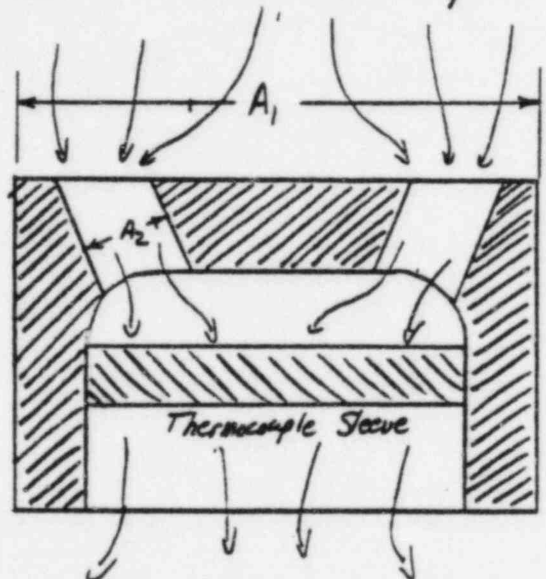
m_r is the ratio of the flow through the cavity created by removing the elements to the flow in the region (it is assumed that a 5 column region is removed since it requires the largest flow increase)

GA 268 (REV. 4/82)

CALCULATION SHEET

CALCULATIONS FOR			
EQUIP. NO.	PROJ.	CALC. NO.	PAGE OF
PREPARED BY	DATE	REF. DOCUMENTS:	
CHECKED BY	DATE	907212 A	

The loss coefficient through the cavity is essentially the loss coefficient through the core support block. The flow path through the core support block is shown schematically below:



Core Support Block

Neglecting friction, turning losses and the loss caused by the presence of the thermocouple sleeve, the loss through the core support block may be considered simply as a contraction from A_1 to A_2, and then an expansion from A_2 to A_1. The area ratio for the contraction and expansion is

$$A_r = \frac{A_2}{A_1} = \frac{(6)(7.55^2)\frac{\pi}{4}}{(7)(14.122^2)\frac{\sqrt{3}}{2}} = \frac{268.62}{1217.56} = 0.22$$

GA 268 (REV. 4/82)

CALCULATION SHEET

CALCULATIONS FOR		907212/A	
EQUIP. NO.	PROJ.	CALC. NO.	PAGE OF
PREPARED BY	DATE	REF. DOCUMENTS:	
CHECKED BY	DATE		

From Compact Heat Exchangers by Kays and London, Fig 5.2, assuming a Reynold's number of 10,000 in A_2:

contraction loss $K_c = 0.41$

expansion loss $K_e = 0.60$

then $K_{CAV} = K_c + K_e = 1.01$

$A_{CAV} = A_2 = 268.62 \text{ in}^2$

Since there is virtually no temperature rise of the cavity flow, the expression for pressure drop for this flow is:

$$\Delta P_{CORE} = \frac{\dot{m}_{CAV}^2}{2 g_c \rho A_{CAV}^2} K_{CAV}$$

Solving for $\dot{m}_{CAV}$:

$$\dot{m}_{CAV} = \left[\frac{2 g_c \rho A_{CAV}^2 \Delta P_{CORE}}{K_{CAV}}\right]^{1/2}$$

$$\dot{m}_{CAV} = 3600 \left[\frac{(2)(32.2)(1217.56/144)^2}{1.01}\right]^{1/2} \sqrt{\rho \Delta P_{CORE}}$$

$$\boxed{\dot{m}_{CAV} = 2.43\ 10^5 \sqrt{\rho \Delta P_{CORE}} \quad \text{lbm/hr}}$$

where ρ is the coolant density at core inlet in lbm/ft^3

ΔP_{CORE} is the core pressure drop in psf.

CALCULATION SHEET

GA 268 (REV. 4/82)

CALCULATIONS FOR			
EQUIP. NO.	PROJ.	CALC. NO.	PAGE OF
PREPARED BY	DATE	REF. DOCUMENTS: [illegible]72127A	
CHECKED BY	DATE		

In the LAMSTAB code the average coolant channel flow rate and core pressure drop are calculated. Core pressure drop is used in the above expression along with ρ (which is input) to solve for m_{CAV}. The flow in the 5 column region is calculated from:

$$m_5 = \frac{(m_{cc})(N5)}{(1 - f_{cx})}$$

$$m_5 = \frac{475.83}{(1 - .025)} m_{cc} = 488.03\ m_{cc}$$

$$\boxed{m_5 = 488.03\ m_{cc}}$$

then $$\boxed{m_r = \frac{m_{CAV}}{m_5} = 498.\ \frac{\sqrt{\rho \Delta P_{core}}}{m_{cc}}}$$

8079121A

Appendix C

LAMSTAB + RJK Code Listing and Sample Input

```
@RUN
@COPY    LAMSTAB*RJK.,TPFS.
@PRT,S   .PUN2
@ADD     .CODE
@ASG,AX  RJK*F2.
@USE     12.,RJK*F2.
@XQT,Q
36.12         0.5           0.5
0.625         187.32        0.625         46.8          0.625         46.8
0.229         2300.0        100.0         50.0            14
3.0           1.61
0.4           1.61
      4
1.0           1.092         1.229         1.458
0.002         250.0         25.0          1.0           0.025         0.0001
0.1           0.01
      1
@PMD,ERE
```

907212/A

```
      C-----------------------------------------------------------------
      C     THE CONSTANTS IN THIS CODE WHICH RELATE CHANNEL FLOW AND
      C     TEMPERATURE RISE TO CORE POWER FRACTION AND CIRC FLOW
      C     FRACTION (LCO 4.1.9-1), OR TO CORE POWER FRACTION AND REGION
      C     TEMPERATURE RISE (LCO 4.1.9-2) ARE DERIVED IN "LCO 4.1.9
      C     REANALYSIS", R. J. KAPERNICK, DOCUMENT NO. 907212, 11/83.
      C-----------------------------------------------------------------
            PARAMETER NT=1500
            DIMENSION PFRAC(NT),DELTR(NT),WFR(NT),FLO(NT),DELTC(NT),
           .          RPF(2),TILT(2),WFRAC(NT),DTMIN(NT),WFMAX(NT),
           .          AO(2),BO(2),REYIN(NT),REYEX(NT),DP(NT),
           .          FLOFAC(10),TINMIN(NT),DEFECT(NT),NITER(NT),
           .          DEFREF(NT),DEFR(NT)
            REAL M,LUR,LLR,LC,LURF,LLRF,LCF,LCF1,LCF2,KIN,KOUT,KORIF
            DATA   AMU/0.00069/     M/0.674/        PI/3.1416/
           .       R/336.3/         CP/1.242/       AO(1)/16.7/
           .       BO(1)/1.0/       AO(2)/0.0195/   BO(2)/0.0985/
           .       ZERO/0.0/
            READ(5,10) KORIF,KIN,KOUT
            READ(5,10) DC,LC,DUR,LUR,DLR,LLR
            READ(5,15) DEN,TRAN,TIN1,DTEMP,NTEMP
            READ(5,10) RPF(1),TILT(1)
            READ(5,10) RPF(2),TILT(2)
            READ(5,20) NCUR
            READ(5,10) (FLOFAC(I),I=1,NCUR)
            READ(5,10) PINC,TSTART,DTNEW,DTINC,WSTART,DWINC
            READ(5,10) FINC1,FINC2
            READ(5,20) NPRT,NREFUL
         10 FORMAT(6F12.5)
         15 FORMAT(4F12.3,I6)
         20 FORMAT(12I6)
      C-----------------------------------------------------------------
      C     SET CORE POWER FRACTIONS FOR WHICH CALCS MAY BE PERFORMED
      C     AND CONVERT UNITS
      C-----------------------------------------------------------------
            PFRAC(1)=PINC
            DO 100 I=2,NT
            PFRAC(I)=PFRAC(I-1)+PINC
        100 CONTINUE
            DCF=DC/12.
            LCF=LC/12.
            DURF=DUR/12.0
            LURF=LUR/12.0
            DLRF=DLR/12.0
            LLRF=LLR/12.0
            AREA=PI*DCF**2./4.0
      C-----------------------------------------------------------------
      C     START OF LCO 4.1.9-2 CALCUALTION
      C     INITIALIZE REGION TEMP RISE LIMIT TO A HIGH VALUE
      C-----------------------------------------------------------------
```

```
      DO 110 I=1,NT
      DTMIN(I)=1000.0
  110 CONTINUE
      NMAX=0
      TIN=TIN1
C-----------------------------------------------------------------
C     LOOP OVER CORE INLET TEMPERATURES
C-----------------------------------------------------------------
      DO 120 ITEMP=1,NTEMP
      TINR=TIN+460.
      PRES=DEN*R*TINR/144.0
      DELTR(1)=TSTART
      NUM=1
C-----------------------------------------------------------------
C     LOOP OVER CORE POWER FRACTION UNTIL POWER/FLOW=1.05
C-----------------------------------------------------------------
      DO 130 I=1,NT
      NITER(I)=0
      NCHK=0
      DEFECT(I)=0.0
C-----------------------------------------------------------------
C     ITERATE ON REGION TEMP RISE TO FIND CRITICAL PRESSURE DROP
C-----------------------------------------------------------------
  140 NITER(I)=NITER(I)+1
C-----------------------------------------------------------------
C     CALCULATE REGION PRESSURE DROP FROM THE AVERAGE POWER CHANNEL
C-----------------------------------------------------------------
      DTC=1.0154*DELTR(I)    @ 1.0154=0.9502/0.9358
     .        *(1.0-SQRT(1.31E-4+2600.0/DELTR(I)**2.))
      FLOW=88775.0*PFRAC(I)*RPF(2)/DELTR(I)
     .      *(1.0-SQRT(6.91E-3+2568.89/DELTR(I)**2.))
      IF(FLOW.GT.0.0.AND.DTC.GT.0.0) GO TO 150
      DELTR(I)=0.0
      DELTR(I+1)=TSTART
      NUM=NUM+1
      GO TO 130
  150 VHIN=(FLOW/AREA)**2./(2.0*32.2*DEN*3600.0**2.)
      TEXR=DTC+TINR
      XMU=AMU*TINR**M
      RYIN=4.0*FLOW/(PI*DCF*XMU)
      XMU=AMU*TEXR**M
      RYEX=4.0*FLOW/(PI*DCF*XMU)
      LIN=1
      LEX=1
      IF(RYIN.GT.TRAN) LIN=2
      IF(RYEX.GT.TRAN) LEX=2
      TUR=4.0*AO(LIN)*RYIN**(-BO(LIN))*(LURF/DURF)
      IF(LIN.NE.LEX) GO TO 160
      TAU=TEXR/TINR
      TC=4.0*AO(LIN)*RYIN**(-BO(LIN))*(LCF/DCF)
     .     *(TAU**(M*BO(LIN)+2.0) -1.0)/((TAU-1.0)*(M*BO(LIN)+2.0))
      GO TO 170
  160 CONTINUE
      TTRAN=((4.0*FLOW)/(AMU*TRAN*PI*DCF))**(1.0/M)
      LCF1=(TTRAN-TINR)/(TEXR-TINR)*LCF
      LCF2=LCF-LCF1
      TAU=TTRAN/TINR
```

```
            TC1=4.0*AO(LIN)*RYIN**(-BO(LIN))*(LCF1/DCF)
     .         *(TAU**(M*BO(LIN)+2.0) -1.0)/((TAU-1.0)*(M*BO(LIN)+2.0))
            TAU=TEXR/TTRAN
            TC2=(TTRAN/TINR)*4.0*AO(LEX)*TRAN**(-BO(LEX))*(LCF2/DCF)
     .         *(TAU**(M*BO(LEX)+2.0) -1.0)/((TAU-1.0)*(M*BO(LEX)+2.0))
            TC=TC1+TC2
        170 TAU=TEXR/TINR
            TLR=TAU*4.0*AO(LEX)*RYEX**(-BO(LEX))*(LLRF/DLRF)
            TREST=2.0*(TAU-1.0)+KIN+KOUT*TAU
            TGRAV=DEN*(LURF+LLRF/TAU+LCF*ALOG(TAU)/(TAU-1.0))
            DP(I)=VHIN*(TUR+TC+TLR+TREST)-TGRAV
      C-----------------------------------------------------------
      C     CALCULATE FLOW RATE IN THE CRITICAL CHANNEL
      C-----------------------------------------------------------
            F2=1.0
            FINC=FINC1
        220 DPCRSV=1.0E9
        230 FLO(I)=FLOW/F2
            DELTC(I)=DTC*TILT(2)*0.9358*F2
            VHIN=(FLO(I)/AREA)**2./(2.0*32.2*DEN*3600.0**2.)
            TEXR=DELTC(I)+TINR
            XMU=AMU*TINR**M
            REYIN(I)=4.0*FLO(I)/(PI*DCF*XMU)
            XMU=AMU*TEXR**M
            REYEX(I)=4.0*FLO(I)/(PI*DCF*XMU)
            LIN=1
            LEX=1
            IF(REYIN(I).GT.TRAN) LIN=2
            IF(REYEX(I).GT.TRAN) LEX=2
            TUR=4.0*AO(LIN)*REYIN(I)**(-BO(LIN))*(LURF/DURF)
            IF(LIN.NE.LEX) GO TO 200
            TAU=TEXR/TINR
            TC=4.0*AO(LIN)*REYIN(I)**(-BO(LIN))*(LCF/DCF)
     .         *(TAU**(M*BO(LIN)+2.0) -1.0)/((TAU-1.0)*(M*BO(LIN)+2.0))
            GO TO 210
        200 CONTINUE
            TTRAN=((4.0*FLO(I))/(AMU*TRAN*PI*DCF))**(1.0/M)
            LCF1=(TTRAN-TINR)/(TEXR-TINR)*LCF
            LCF2=LCF-LCF1
            TAU=TTRAN/TINR
            TC1=4.0*AO(LIN)*REYIN(I)**(-BO(LIN))*(LCF1/DCF)
     .         *(TAU**(M*BO(LIN)+2.0) -1.0)/((TAU-1.0)*(M*BO(LIN)+2.0))
            TAU=TEXR/TTRAN
            TC2=(TTRAN/TINR)*4.0*AO(LEX)*TRAN**(-BO(LEX))*(LCF2/DCF)
     .         *(TAU**(M*BO(LEX)+2.0) -1.0)/((TAU-1.0)*(M*BO(LEX)+2.0))
            TC=TC1+TC2
        210 TAU=TEXR/TINR
            TLR=TAU*4.0*AO(LEX)*REYEX(I)**(-BO(LEX))*(LLRF/DLRF)
            TREST=2.0*(TAU-1.0)+KIN+KOUT*TAU
            TGRAV=DEN*(LURF+LLRF/TAU+LCF*ALOG(TAU)/(TAU-1.0))
            DPCRIT=VHIN*(TUR+TC+TLR+TREST)-TGRAV
      C-----------------------------------------------------------
      C     CHECK ON FLOW RATE CONVERGENCE
      C-----------------------------------------------------------
            IF(DPCRIT.LT.DP(I)) GO TO 240
            IF(DPCRIT.GT.DPCRSV) GO TO 250
            DPCRSV=DPCRIT
```

```
      F2=F2+FINC
      GO TO 230
  240 IF(FINC.LT.FINC1) GO TO 260
      F2=F2-FINC
      FINC=FINC2
      GO TO 220
C-----------------------------------------------------------------
C     CHECK ON CRITICAL CORE PRESSURE DROP CONVERGENCE
C     GO TO NCHK=3 TO BE SURE TO SKIP STEP INCREASES IN PRESSURE
C     DROP DUE TO TRANSITION TO TURBULENT FLOW IN THE UPPER AND
C     LOWER REFLECTORS
C-----------------------------------------------------------------
  260 IF(NITER(I).EQ.1) GO TO 250
      IF(DP(I).GE.DPSAV.AND.FLO(I).GE.FLOSAV) NCHK=NCHK+1
      IF(NCHK.EQ.3) GO TO 180
  250 FLOSAV=FLO(I)
      DPSAV=DP(I)
      DELTR(I)=DELTR(I)-DTINC
      GO TO 140
C-----------------------------------------------------------------
C     IF CONVERGES ON FIRST OPPORTUNITY, MAY NOT HAVE STARTED
C     THE ITERATION IN THE UNSTABLE REGIME
C-----------------------------------------------------------------
  180 IF((NITER(I)-NCHK).GT.1) GO TO 270
      DELTR(I)=DELTR(I)+3.0*DTINC+DTNEW
      NITER(I)=0
      NCHK=0
      GO TO 140
  270 DEFECT(I)=FLOW/FLO(I)
      DELTR(I+1)=DELTR(I)+DTNEW
      CTSL=DELTR(I)/710.0
C-----------------------------------------------------------------
C     CHECK IF POWER/FLOW > 1.05
C-----------------------------------------------------------------
      IF(CTSL.LT.1.05) GO TO 280
      DELTR(I)=710.0*1.05
      ITEM=I
C-----------------------------------------------------------------
C     PER PSC REQUEST, TAKE LIMIT OUT TO AT LEAST 15% POWER
C-----------------------------------------------------------------
  290 IF(PFRAC(ITEM).GE.0.14999) GO TO 300
      ITEM=ITEM+1
      NUM=NUM+1
      DELTR(ITEM)=710.0*1.05
      GO TO 290
  280 NUM=NUM+1
  130 CONTINUE
  300 CONTINUE
      MXITEM=MAX0(ITEM,MXITEM)
      IF(NPRT.EQ.0) GO TO 320
C-----------------------------------------------------------------
C     PRINT RESULTS FOR EACH CORE INLET TEMPERATURE
C-----------------------------------------------------------------
      WRITE(6,25) TIN,PRES,TRAN
   25 FORMAT(1H1/'   TIN = ',F5.1/'  PRES = ',F5.1/'  REYTR = ',F5.0//)
      I1=1
      I2=MIN0(50,NUM)
```

```
      310 WRITE(6,30) (PFRAC(I),DELTR(I),FLO(I),DELTC(I),REYIN(I),
     *                REYEX(I),DEFECT(I),DP(I),NITER(I),I=I1,I2)
       30 FORMAT('  PFRAC    DELTR    FLOW    DELTC     REYIN    REYEX   DEFECT'
     *       ,'      DP    NITER'/(F7.3,F9.1,F8.3,F8.1,2F9.0,F8.3,
     *       F9.3,I6))
          I1=I1+50
          IF(I1.GT.NUM) GO TO 320
          I2=MIN0(I2+50,NUM)
          WRITE(6,35)
       35 FORMAT(1H1)
          GO TO 310
      320 CONTINUE
          NMAX=MAX0(NMAX,NUM)
C-----------------------------------------------------------------------
C         UPDATE TEMP RISE LIMIT IF RESULTS FROM NEW CALCULATION
C         (CORE INLET TEMPERATURE) ARE MORE RESTRICTIVE
C-----------------------------------------------------------------------
          DO 330 INUM=1,NUM
          IF(DELTR(INUM).GT.DTMIN(INUM)) GO TO 330
          DTMIN(INUM)=DELTR(INUM)
          TINMIN(INUM)=TIN
      330 CONTINUE
      120 TIN=TIN+DTEMP
C-----------------------------------------------------------------------
C         WRITE RESULTS ON FILE FOR PLOTTING
C-----------------------------------------------------------------------
          NMAX1=NMAX+1
          WRITE(12,40) NMAX1,ZERO,(PFRAC(LP),LP=1,NMAX)
          WRITE(12,45) NMAX1,ZERO,(DTMIN(LP),LP=1,NMAX)
       40 FORMAT(I6/(6F7.4))
       45 FORMAT(I6/(6F7.1))
C-----------------------------------------------------------------------
C         PRINT FINAL LIMIT FOR LCO 4.1.9-2
C-----------------------------------------------------------------------
          I1=1
          I2=MIN0(50,NUM)
      340 WRITE(6,50) (PFRAC(LP),DTMIN(LP),TINMIN(LP),LP=I1,I2)
       50 FORMAT(1H1,'  PFRAC    DTMIN      TIN'/(F7.3,F9.1,F8.0))
          I1=I1+50
          IF(I1.GT.NUM) GO TO 350
          I2=MIN0(I2+50,NUM)
          GO TO 340
      350 CONTINUE
C-----------------------------------------------------------------------
C         START OF LCO 4.1.9-1 CALCUALTION
C         INITIALIZE CIRC FLOW FRACTION TO ZERO
C-----------------------------------------------------------------------
          DO 360 I=1,NT
          WFMAX(I)=0.0
      360 CONTINUE
          NMAX=0
          TIN=TIN1
C-----------------------------------------------------------------------
C         LOOP OVER CORE INLET TEMPERATURES
C-----------------------------------------------------------------------
          DO 370 ITEMP=1,NTEMP
          TINR=TIN+460.
```

```
      PRES=DEN*R*TINR/144.0
      WFRAC(1)=WSTART
      NUM=1
C-----------------------------------------------------------------------
C     LOOP OVER CORE POWER FRACTION UNTIL POWER/FLOW=1.05
C-----------------------------------------------------------------------
      DO 380 I=1,NT
      NITER(I)=0
      NCHK=0
      DEFECT(I)=0.0
C-----------------------------------------------------------------------
C     ITERATE ON CIRC FLOW FRACTION TO FIND CRITICAL PRESSURE DROP
C-----------------------------------------------------------------------
  390 NITER(I)=NITER(I)+1
C-----------------------------------------------------------------------
C     CALCULATE CORE PRESSURE DROP FROM THE AVERAGE POWER CHANNNEL
C-----------------------------------------------------------------------
      FLOW=114.74*WFRAC(I)*(1.0-0.0831)
      DTC=785.62*PFRAC(I)/WFRAC(I)    @ 785.62=735.18/0.9358
     .    *(1.0-SQRT(1.31E-4+2.82E-4*(WFRAC(I)/PFRAC(I))**2.))
      IF(DTC.GT.1.0) GO TO 400
      WFRAC(I)=1.0
      WFRAC(I+1)=WSTART
      NUM=NUM+1
      GO TO 380
  400 VHIN=(FLOW/AREA)**2./(2.0*32.2*DEN*3600.0**2.)
      TEXR=DTC+TINR
      XMU=AMU*TINR**M
      RYIN=4.0*FLOW/(PI*DCF*XMU)
      XMU=AMU*TEXR**M
      RYEX=4.0*FLOW/(PI*DCF*XMU)
      LIN=1
      LEX=1
      IF(RYIN.GT.TRAN) LIN=2
      IF(RYEX.GT.TRAN) LEX=2
      TUR=4.0*AO(LIN)*RYIN**(-BO(LIN))*(LURF/DURF)
      IF(LIN.NE.LEX) GO TO 410
      TAU=TEXR/TINR
      TC=4.0*AO(LIN)*RYIN**(-BO(LIN))*(LCF/DCF)
     .    *(TAU**(M*BO(LIN)+2.0) -1.0)/((TAU-1.0)*(M*BO(LIN)+2.0))
      GO TO 420
  410 CONTINUE
      TTRAN=((4.0*FLOW)/(AMU*TRAN*PI*DCF))**(1.0/M)
      LCF1=(TTRAN-TINR)/(TEXR-TINR)*LCF
      LCF2=LCF-LCF1
      TAU=TTRAN/TINR
      TC1=4.0*AO(LIN)*RYIN**(-BO(LIN))*(LCF1/DCF)
     .    *(TAU**(M*BO(LIN)+2.0) -1.0)/((TAU-1.0)*(M*BO(LIN)+2.0))
      TAU=TEXR/TTRAN
      TC2=(TTRAN/TINR)*4.0*AO(LEX)*TRAN**(-BO(LEX))*(LCF2/DCF)
     .    *(TAU**(M*BO(LEX)+2.0) -1.0)/((TAU-1.0)*(M*BO(LEX)+2.0))
      TC=TC1+TC2
  420 TAU=TEXR/TINR
      TLR=TAU*4.0*AO(LEX)*RYEX**(-BO(LEX))*(LLRF/DLRF)
      TREST=2.0*(TAU-1.0)+KORIF+KIN+KOUT*TAU
      TGRAV=DEN*(LURF+LLRF/TAU+LCF*ALOG(TAU)/(TAU-1.0))
      DP(I)=VHIN*(TUR+TC+TLR+TREST)-TGRAV
```

```
C-----------------------------------------------------------------------
C      CALCULATE FLOW RATE IN THE CRITICAL CHANNEL
C-----------------------------------------------------------------------
      F1=1.0
      FINC=FINC1
  510 DPCRSV=1.0E9
  500 FLO(I)=FLOW/F1
      DELTC(I)=DTC*RPF(1)*TILT(1)*0.9358*F1
      VHIN=(FLO(I)/AREA)**2./(2.0*32.2*DEN*3600.0**2.)
      TEXR=DELTC(I)+TINR
      XMU=AMU*TINR**M
      REYIN(I)=4.0*FLO(I)/(PI*DCF*XMU)
      XMU=AMU*TEXR**M
      REYEX(I)=4.0*FLO(I)/(PI*DCF*XMU)
      LIN=1
      LEX=1
      IF(REYIN(I).GT.TRAN) LIN=2
      IF(REYEX(I).GT.TRAN) LEX=2
      TUR=4.0*AO(LIN)*REYIN(I)**(-BO(LIN))*(LURF/DURF)
      IF(LIN.NE.LEX) GO TO 450
      TAU=TEXR/TINR
      TC=4.0*AO(LIN)*REYIN(I)**(-BO(LIN))*(LCF/DCF)
     .   *(TAU**(M*BO(LIN)+2.0) -1.0)/((TAU-1.0)*(M*BO(LIN)+2.0))
      GO TO 460
  450 CONTINUE
      TTRAN=((4.0*FLO(I))/(AMU*TRAN*PI*DCF))**(1.0/M)
      LCF1=(TTRAN-TINR)/(TEXR-TINR)*LCF
      LCF2=LCF-LCF1
      TAU=TTRAN/TINR
      TC1=4.0*AO(LIN)*REYIN(I)**(-BO(LIN))*(LCF1/DCF)
     .    *(TAU**(M*BO(LIN)+2.0) -1.0)/((TAU-1.0)*(M*BO(LIN)+2.0))
      TAU=TEXR/TTRAN
      TC2=(TTRAN/TINR)*4.0*AO(LEX)*TRAN**(-BO(LEX))*(LCF2/DCF)
     .    *(TAU**(M*BO(LEX)+2.0) -1.0)/((TAU-1.0)*(M*BO(LEX)+2.0))
      TC=TC1+TC2
  460 TAU=TEXR/TINR
      TLR=TAU*4.0*AO(LEX)*REYEX(I)**(-BO(LEX))*(LLRF/DLRF)
      TREST=2.0*(TAU-1.0)+KORIF+KIN+KOUT*TAU
      TGRAV=DEN*(LURF+LLRF/TAU+LCF*ALOG(TAU)/(TAU-1.0))
      DPTOT=VHIN*(TUR+TC+TLR+TREST)-TGRAV
      DPCRIT=DPTOT-VHIN*KORIF
C-----------------------------------------------------------------------
C     CHECK ON FLOW RATE CONVERGENCE
C-----------------------------------------------------------------------
      IF(DPTOT.LT.DP(I)) GO TO 490
      IF(DPTOT.GT.DPCRSV) GO TO 470
      DPCRSV=DPTOT
      F1=F1+FINC
      GO TO 500
  490 IF(FINC.LT.FINC1) GO TO 480
      F1=F1-FINC
      FINC=FINC2
      GO TO 510
C-----------------------------------------------------------------------
C     CHECK ON CRITICAL CORE PRESSURE DROP CONVERGENCE
C     GO TO NCHK=3 TO BE SURE TO SKIP STEP INCREASES IN PRESSURE
C     DROP DUE TO TRANSITION TO TURBULENT FLOW IN THE UPPER AND
```

```
      C     LOWER REFLECTORS
      C-----------------------------------------------------------------
  480 IF(NITER(I).EQ.1) GO TO 470
      IF(DPCRIT.GE.DPSAV.AND.FLO(I).GE.FLOSAV) NCHK=NCHK+1
      IF(NCHK.EQ.3) GO TO 430
  470 FLOSAV=FLO(I)
      DPSAV=DPCRIT
      WFRAC(I)=WFRAC(I)+DWINC
      GO TO 390
      C-----------------------------------------------------------------
      C     IF CONVERGES ON FIRST OPPORTUNITY, MAY NOT HAVE STARTED
      C     THE ITERATION IN THE UNSTABLE REGIME
      C-----------------------------------------------------------------
  430 IF((NITER(I)-NCHK).GT.1) GO TO 520
      WFRAC(I)=WFRAC(I)-3.0*DWINC-WSTART/2.0
      IF(WFRAC(I).LE.0.0) WFRAC(I)=DWINC
      NITER(I)=0
      NCHK=0
      GO TO 390
  520 DEFECT(I)=FLOW/FLO(I)
      DPTOT=AMAX1(0.0,DPTOT)
      XMR=498.0*SQRT(DEN*DPTOT)/FLOW
      XMR=AMAX1(1.0,XMR)
      IF(NREFUL.NE.0) DEFREF(I)=(49.5175+XMR)/50.5175
      WFRAC(I+1)=WFRAC(I)-5.0*DWINC
      CTSL=PFRAC(I)/WFRAC(I)
      PFMAX=PFRAC(MXITEM)-1.0E-5
      C-----------------------------------------------------------------
      C     CHECK IF POWER/FLOW > 1.05
      C     TAKE LIMIT OUT TO AT LEAST THAT REQUIRED FOR LCO 4.1.9-2
      C-----------------------------------------------------------------
      IF(CTSL.GT.1.05.AND.PFRAC(I).GT.PFMAX) GO TO 530
      NUM=NUM+1
  380 CONTINUE
  530 CONTINUE
      IF(NPRT.EQ.0) GO TO 550
      C-----------------------------------------------------------------
      C     PRINT RESULTS FOR EACH CORE INLET TEMPERATURE
      C-----------------------------------------------------------------
      WRITE(6,25) TIN,PRES,TRAN
      I1=1
      I2=MIN0(50,NUM)
  540 WRITE(6,55) (PFRAC(I),WFRAC(I),FLO(I),DELTC(I),REYIN(I),
     .                REYEX(I),DEFECT(I),DP(I),NITER(I),DEFREF(I),I=I1,I2)
   55 FORMAT('  PFRAC   WFRAC    FLOW    DELTC     REYIN   REYEX  DEFECT'
     .       ,'      DP    NITER  DEFREF'/(F7.3,2F8.4,F8.1,2F8.0,F8.3,
     .       F9.3,I6,F9.3))
      I1=I1+50
      IF(I1.GT.NUM) GO TO 550
      I2=MIN0(I2+50,NUM)
      WRITE(6,35)
      GO TO 540
  550 CONTINUE
      NMAX=MAX0(NMAX,NUM)
      C-----------------------------------------------------------------
      C     UPDATE CIRC FLOW FRACTION LIMIT IF RESULTS FROM NEW CALCULATION
      C     (CORE INLET TEMPERATURE) ARE MORE RESTRICTIVE
```

```
      C-----------------------------------------------------------------
            DO 560 INUM=1,NUM
            IF(WFRAC(INUM).LT.WFMAX(INUM)) GO TO 560
            WFMAX(INUM)=WFRAC(INUM)
            TINMIN(INUM)=TIN
            DEFR(INUM)=DEFREF(INUM)
        560 CONTINUE
        370 TIN=TIN+DTEMP
      C-----------------------------------------------------------------
      C     WRITE RESULTS ON FILE FOR PLOTTING
      C-----------------------------------------------------------------
            NMAX1=NMAX+1
            WRITE(12,40) NMAX1,ZERO,(PFRAC(LP),LP=1,NMAX)
            DO 570 ICUR=1,NCUR
            DO 580 LP=1,NMAX
            WFR(LP)=FLOFAC(ICUR)*WFMAX(LP)
            WFRMAX=PFRAC(LP)/1.05
            WFR(LP)=AMAX1(WFRMAX,WFR(LP))
        580 CONTINUE
            WRITE(12,40) NMAX1,ZERO,(WFR(LP),LP=1,NMAX)
        570 CONTINUE
            IF(NREFUL.EQ.0) GO TO 600
            DO 610 ICUR=1,NCUR
            DO 620 LP=1,NMAX
            WFR(LP)=FLOFAC(ICUR)*WFMAX(LP)*DEFR(I)
            WFRMAX=PFRAC(LP)/1.05
            WFR(LP)=AMAX1(WFRMAX,WFR(LP))
        620 CONTINUE
            WRITE(12,40) NMAX1,ZERO,(WFR(LP),LP=1,NMAX)
        610 CONTINUE
        600 CONTINUE
      C-----------------------------------------------------------------
      C     PRINT FINAL LIMIT FOR LCO 4.1.9-1
      C-----------------------------------------------------------------
            DO 590 LP=1,NMAX
            WFRMAX=PFRAC(LP)/1.05
            WFMAX(LP)=AMAX1(WFRMAX,WFMAX(LP))
        590 CONTINUE
            I1=1
            I2=MIN0(50,NUM)
        630 WRITE(6,60) (PFRAC(LP),WFMAX(LP),TINMIN(LP),LP=I1,I2)
         60 FORMAT(1H1,'  PFRAC    WFMAX     TIN'/(F7.3,F9.4,F8.0))
            I1=I1+50
            IF(I1.GT.NUM) GO TO 640
            I2=MIN0(I2+50,NUM)
            GO TO 630
        640 CONTINUE
            END
```

ATTACHMENT 3

SIGNIFICANT HAZARDS

CONSIDERATIONS ANALYSIS

SIGNIFICANT HAZARDS CONSIDERATIONS ANALYSIS

Since the proposed amendment to LCO 4.1.9 serves to define new operating limits which correct for non-conservative errors and omissions in the development of the orignial limits, operation of the facility in accordance with the proposed amendment will not (1) involve an increase in the probability or consequences of an accident previously evaluated, (2) create the possibility of a new or different kind of accident from any accident previously evaluated, or (3) involve a reduction in a margin of safety. It is therefore concluded that the proposed amendment involves no significant hazards considerations.

Basis for Specification LCO 4.1.8

An unexpected and/or unexplained change in the observed core reactivity could be indicative of the existence of potential safety problems or of operational problems. Any reactivity anomaly greater than 0.01 ΔK would be unexpected, and its occurrence would be thoroughly investigated and evaluated. The value of 0.01 Δk is considered to be a safe limit since a shutdown margin of at least 0.01 Δk with the highest worth rod pair fully withdrawn is always maintained (see LCO 4.1.2).

Specification LCO 4.1.9 - Core Region Temperature Rise, Limiting Condition for Operation

Whenever core inlet orifice valves are set for equal region flows, the total circulator flow rate shall be above the minimums given in Figure 4.1.9-1 (at the appropriate helium density and power level). Whenever the core inlet orifice valves are set at any positions other than for equal region flows, the measured helium coolant temperature rise through any core region shall not exceed the limits given in Figure 4.1.9-2 (at the appropriate helium density and power level).

If the measured helium coolant temperature rise exceeds the allowable limits or the minimum total circulator flow rate is not available, immediate corrective action shall be taken. If this corrective action is not successful within fifteen (15) minutes, an immediate orderly shutdown shall be initiated.

When the reactor is already shutdown and it is necessary to terminate the helium flow for short time periods, the amount of thermal energy from fission product decay must be sufficiently low to prevent the average core temperature from exceeding 760°F during the period of no flow.

Basis for Specification LCO 4.1.9

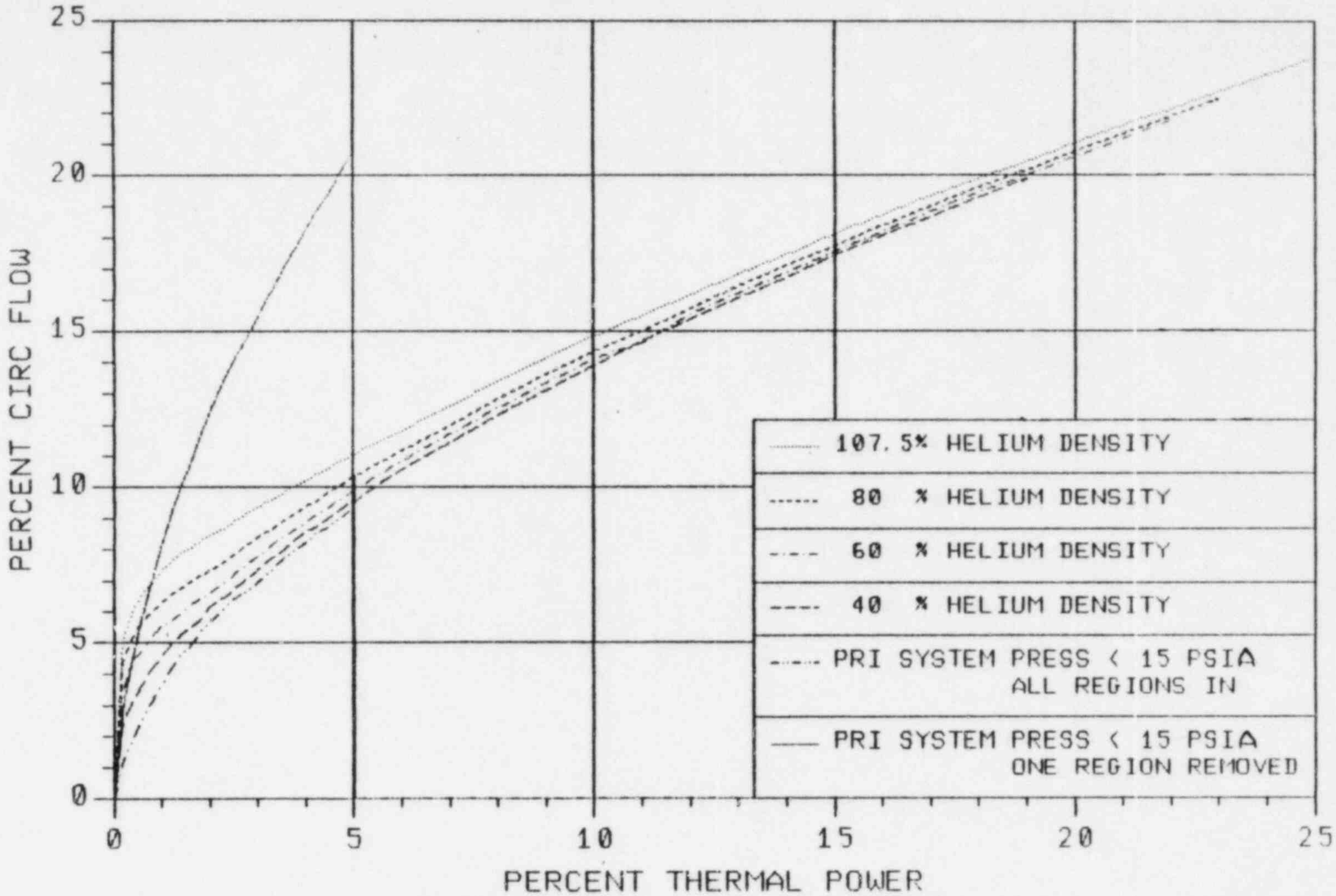
The intent of this specification is to assure that there is an adequate helium coolant flow rate through all core coolant channels, particularly for low power and flow conditions. This is accomplished by specifying either a minimum total circulator flow rate, or a maximum core region coolant temperature rise for various thermal power levels (including power from decay heat).

Very low helium coolant flow rates may result in laminar flow conditions with resultant high friction factors and low heat transfer film coefficients and potential for possible local helium flow stagnation, which could result in excessive fuel temperatures.

The minimum total circulator flow and maximum core region helium temperature rise limits have been developed based upon a number of conservative assumptions. The maximum column to region average power peaking factor was assumed to be 1.61 which is consistent with LCO 4.1.3. The analysis for full density conditions assumed the maximum permissible primary coolant inventory of 107.5% specified in LCO 4.4.1. The analysis was performed for each power level at a core inlet temperature of 100°F, and then in increments of 50°F up to 750°F. The most restrictive of these calculations at each power level were utilized to form the limits. Model uncertainties and measurement errors were factored into the analysis.

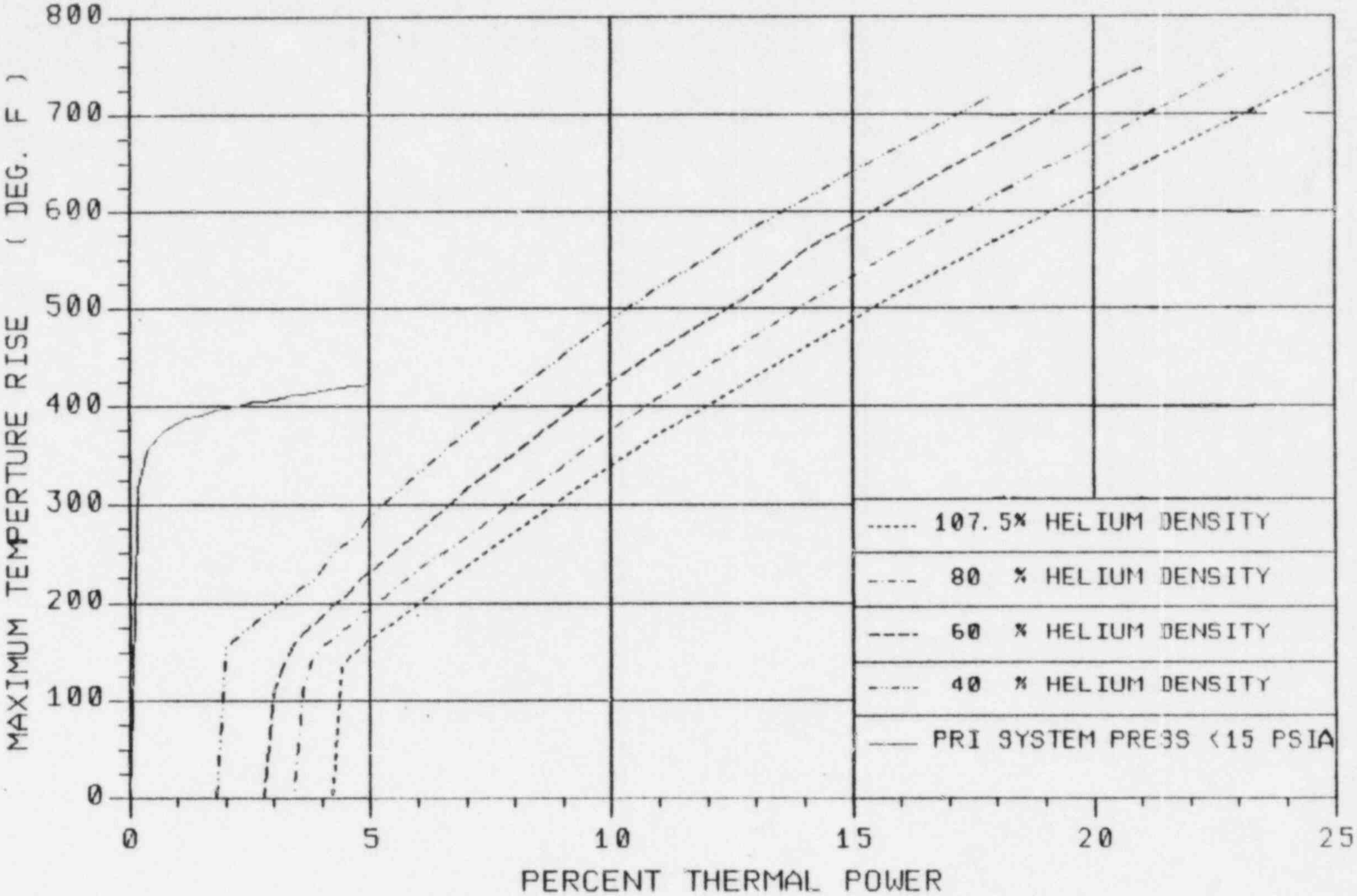
Even with the reactor shutdown, some helium coolant flow must be provided to remove the heat from fission product decay. The flow must be sufficient to prevent the helium inlet temperature from exceeding 760°F to prevent damage to the reactor internals. If the flow is terminated for short periods and the average core temperature does not exceed 760°F, the helium inlet temperature will be acceptable when the flow is resumed.

Figure 4.1.9-1



$$\%\ \text{Helium Density} = \frac{0.373\ [\text{Reactor Press (psia)} / (\text{Circ Inlet Temp } (°F + 460))]}{0.00213}$$

Figure 4.1.9-2



$$\% \text{ Helium Density} = \frac{0.373\ [\text{Reactor press (psia)} / (\text{Circ Inlet Temp } (°F + 460)]}{0.00213}$$